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NASA CR 66299

FEASIBILITY STUDY FOR DEVELOPMENT OF A FLEXIBLE REINFORCED WINDOW

by

Robert C. Kohrn
George E. Kelsheimer
Edwin C. Uhlig
Becky S. LaBelle

Prepared under Contract No. NASI-5524 by
UNIROYAL - U.S. Rubber Company
Mishawaka, Indiana

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Langley Research Center
Langley Station
Hampton, Virginia

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ADMINISTRATIVE INFORMATION

This report was prepared by the Engineered Systems Department of the UNIROYAL - U. S. Rubber Company, Mishawaka, Indiana, under National Aeronautics and Space Administration Contract NASI-5524.

The contract for Feasibility Study for Development of a Flexible Reinforced Window was administered under the direction of Mr. Jerry G. Williams of the National Aeronautics and Space Administration, Langley Research Center, Langley Station, Hampton, Virginia.

The final report covers the period of 7 September 1965 to 7 December 1966.

This report was compiled and prepared by George E. Kelsheimer, Edwin C. Uhlig, and Becky S. LaBelle, under the direction and approval of R. C. Kohrn, Manager, Engineered Systems Department, UNIROYAL - U. S. Rubber Company.

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SUMMARY

The major objective of this program was to develop a flexible transparent material which could become an integral part of the flexible wall of an expandable fiber reinforced elastomeric structure.

PHASE I of the program involved materials selection and evaluation to develop an optically transparent flexible sheet material suitable for use as a window in a flexible expandable space structure. This included feasibility study and materials evaluation to define the technical problems, determination of the solutions to these problems, and analysis of technical areas such as materials selection, filament spacing and patterns, and methods of attachment of the flexible transparent material to the pressure vessel.

PHASE II included the fabrication and experimental evaluation of flat sheet and cylindrical sections constructed of materials selected from PHASE I and attached by concepts designed in PHASE II. These materials were pressure loaded in test fixtures and evaluated to determine their strength and optical characteristics under loaded conditions.

PHASE III included the design, fabrication and experimental evaluation of three scale model filament-wound cylindrical chambers with hemispherical ends, each incorporating a flexible transparent window in the cylindrical section. Materials and attachment methods used for the flexible window were selected from the evaluation of PHASES I and II.

The following technical guidelines were provided to assist in establishing design parameters.

a. The materials were assumed to be exposed to the space environment including: hard vacuum temperature extremes, micrometeoroids, and radiation (ultraviolet and particulate).

b. An ultimate strength goal of at least 840 lb./in. in the direction of maximum stress was considered as the design requirement for the flexible transparent composite material.

c. Blow-out strength of the window polymer was based on a 7.0 psi working pressure load with a safety factor of 5.

d. The transparent composite material was designed to exhibit good optical characteristics under a pressure differential of 7.0 psi.

INTRODUCTION

Advanced manned space programs indicate a requirement for visual observation of experiments and subsystems located exterior to the space structure. Several of these proposed space structures are flexible, expandable concepts; for example, lunar shelters, airlocks and tunnels. NASA Contracts for the conceptual study and design of such structures include: (1) NASI - 4277, "Feasibility Study and Conceptual Design of Expandable Modules for Lunar Surface Operation", (2) NASI - 6673, "A Feasibility Investigation of Expandable Structures Module for Orbital Experiment - Artificial G", and (3) NASI - 5572 "Design and Construction of an Expandable Air Lock". A flexible transparent window integrated into such expandable structures can provide the necessary capability for visual observations of exterior equipment and experiments.

It was therefore found necessary to develop the technology for making a flexible transparent material which could become an integral part of the flexible wall of an expandable structure. Known flexible transparent elastomeric materials do not possess sufficient strength characteristics to resist the pressure loads applied to a manned space structure. However, a very promising concept for meeting the optical and strength requirements of a flexible transparent material is that of reinforcing flexible transparent elastomers with a grid pattern of filaments. To optimize the optical characteristics for the loads applied, a parametric evaluation of such variables as grid pattern and spacing, composite thickness, and the effect of environmental conditions was required. Areas requiring investigation included materials selection and fabrication, and attachment design.

The objective of the study was to establish the technical feasibility of providing a high strength flexible transparent composite, to investigate means of attaching such a composite as a part of an expandable structure, and to demonstrate the practical application of the concept in a scale model pressure vessel.

LIST OF SYMBOLS USED IN TEXT

a	width of unsupported matrix membrane between filament reinforcements (inches)
c	chord length of arc (inches)
d	diameter of arc (inches)
E	100% tensile modulus of elasticity of matrix (psi)
e_a	ends per inch width of axial ribbon
e_g	ends per inch width of cylinder
e_r	glass ends required in reinforcement doilies
Fr	force developed in reinforcing doilies per axial width of doily (pounds)
h	maximum distance between arc and chord (inches)
n_a	number of single axial plies
n_g	number of single girth plies
r	radius of cylinder (inches)
p	internal pressure (psi)
psi	pounds per square inch
RMS	root mean square
R_p	radius of window plus one-half width of reinforced doily
RTV	room temperature vulcanizing
s_a	axial strength required in pounds per inch of circumference (pounds)
s_g	girth strength required in pounds per inch of cylinder length (pounds)

s_{ga}	girth reinforcement from axial windings, pounds per inch of cylinder length
s_{gt}	total girth stress (pounds)
t	plate thickness (inches)
t_e	working glass end tensile (psi)
ϕ	winding angle (11.5°)
θ	winding angle (90°)
w	unit force on membrane (psi)
$m\mu$	millimicron

PHASE I

MATERIALS SELECTION AND EVALUATION

SELECTION OF OPTICALLY TRANSPARENT POLYMERS

Eight polymers were evaluated representing four generically different types. Two polymers from each of the four generic types were evaluated based upon their apparent optical clarity and other physical properties. Where necessary, appropriate additives were incorporated into the polymers to improve their clarity, curing characteristics, or physical properties. The four generic types of polymers evaluated within each type are shown in Table 1.

TABLE 1. OPTICALLY TRANSPARENT POLYMERS

Polymer	Source
<u>Ethylene - Propylene</u>	
Ethelene Propylene Copolymer Res. Cen. 82665	UniRoyal-U. S. Rubber Co.
Ethylene Propylene Terpolymer Nordel 1040	Dupont
<u>Urethane</u>	
Millable Polyester - Estane 5740X140	B. F. Goodrich
Castable Polyurethanes - Vibrathanes	Naugatuck Chem. Co.
V-6001R/V-3005 (Polyester)	
V-6005/Curalon M (Polyester)	
V-6008/Curalon M (Polyester)	
V-B600/Curalon M (Polyether)	
<u>Silicone</u>	
Compound #1 Dimethyl RTV Silicone #615	General Electric
Compound #2 Dimethyl RTV Silicone - Sylgard 184	Dow-Corning
<u>Isoprene</u>	
Compound #1 Polyisoprene #309	Shell Chemical Co.
Compound #2 Polyisoprene #310	Shell Chemical Co.

Table 2 presents the polymers and additives used in selecting the polymers for end use application in this evaluation. Although both castable and millable urethane polymers are shown in Table 1, only the millable urethane polymer is shown in Table 2. Several castable urethanes, both polyester and polyether types, were evaluated. The castable urethanes which exhibited the required degree of transparency had too short a "pot life" to be practical for application to the window concept. It was found that entrapped air within the casting could not be removed prior to setting of the panels. Solvent casting of the urethanes yielded only distorted and "orange peel" surface panels in the thicknesses required. For this reason, the polyurethane work was concentrated on a high transparency millable, moldable urethane.

TABLE 2. POLYMER FORMULATION*

Polymer	Formula Identification						
	66-024	66-025	66-026	66-027	66-028	A-D 66-029	66-030
Ethylene/Propylene Copolymer	100	-	-	-	-	-	-
Ethylene/Propylene Terpolymer	-	-	-	100	-	-	-
Urethane-Millable Polyester	-	-	-	-	100	-	-
Cpd. #1 Dimethyl RTV Silicone (Part A)	-	-	-	-	-	100	-
Cpd. #1 Dimethyl RTV Silicone (Part B)	-	-	-	-	-	10	-
Cpd. #2 Dimethyl RTV Silicone (Part A)	-	-	-	-	-	-	100
Cpd. #2 Dimethyl RTV Silicone (Part B)	-	-	-	-	-	-	10
Cpd. #1 Polyisoprene	-	100	-	-	-	-	-
Cpd. #2 Polyisoprene	-	-	100	-	-	-	-
Additives							
Oxirone 2000	2	-	-	2	-	-	-
Buton 150	3	-	-	3	-	-	-
Cab-O-Sil	20	-	-	20	-	-	-
Agerite Geltrol	0.3	-	-	-	-	-	-
Dilauryl Thiodipropionate	0.2	-	-	-	-	-	-
Varox (Liquid)	1.25	1.25	1.25	-	-	-	-
Cyasorb UV-9	-	0.6	0.6	-	-	-	-
Antioxidant 2246	-	-	-	-	0.25	-	-

*All units parts by weight.

POLYMER EVALUATION TEST PROGRAM

The candidate polymers formulated as shown in Table 2 were molded or cast, as applicable to the polymer, into sheets 15" x 15" square in three thicknesses of approximately 0.030", 0.060", and 0.120" respectively. The test sheets were produced in 0.031", 0.062", and 0.125" thick picture frame molds. The products from the molds were evaluated on the basis of the thickness obtained. Departure from the specified thickness was due to side effects produced due either to molding pressure or mold loading. Thickness variations from edge to edge of the molded sheets were also encountered. Quantities of material, in some instances, and time in all instances did not allow for the determination of optimum time-temperature-pressure-load factors to produce test sheets of exactly the stipulated thickness. The polymers molded into test sheets as described above were evaluated according to the criteria shown in Table 3. The tests stipulated in this table were performed as follows:

Surface Finish

Surface finish was a visual test performed on all samples. The test sheets were molded or cast against highly polished Ferro-type plates, such as those used by photographers in making glossy prints, or a highly polished chrome-plated steel plate having a 1/2 RMS finish. All samples as molded or cast exhibited a smooth, clear surface. After aging, many of the samples exhibited crazing, cracking, or opacity as noted in Table 4.

Stress/Strain

This test was performed utilizing an Instron Test machine operating at a jaw separation rate of 12 inches per minute. The test was run according to ASTM method D 412-64T utilizing die "C" having a 1/4" wide constricted area. Specimen strain was measured manually. Test results are shown in Table 4.

Glass Clarity

The light transmission qualities of the polymers, in sheet form, were determined over the full range of the visible spectrum (380 mμ - 700 mμ) utilizing a General Electric "Recording Spectrophotometer." (See Tables 5, 6 and 7.) The "Recording Spectrophotometer" consists of three essential units - the monochrometer, the photometer, and a recorder. The monochrometer breaks up the white light into the spectrum colors, each at a band width of 10 millimicrons. The photometer system illuminates the sample (either by transmittance or reflectance) with monochromatic light and furnishes a measurement signal of this light to the recorder.

TABLE 3. NONREINFORCED POLYMER MATERIAL EVALUATION**

Sample Condition	Surface Finish	Stress/Strain	% Glass Clarity	Optical Quality Test	Perme-ability	Flexi-bility
Unaged	*	*	*	*	*	*
Aged 7 days, Oven at 100°C	*	*	*	*	*	*
Aged, Fadeometer***	*	*	*	*	*	*

*Test performed.

**All testing performed at ambient conditions.

***Ultraviolet exposure equivalent to 30 days in a 300 nautical mile earth orbit.

NOTE

Test specimens were subjected to "UV" exposure for 240 hours (10 days) in an Atlas Fadeometer, Model #18-F. Based upon the calculations, presented below, 240 hours in the Fadeometer are equivalent to the "UV" exposure experienced during 29 days in orbit.

Factors Used in Calculations:

1. Approximately 9.03% of the sunlight outside of atmosphere is below 0.4μ wavelength and may degrade materials. ("Space Materials Handbook", 2nd edition, Technical Documentary Report ML-TDR-64-40, Page 33 "Solar Spectral Irradiance Data".)
2. 33.9 watts/ft^2 below 0.4μ is produced by the Fadeometer. ("Atlas Fade-Ometer Brochure", 1962, Page 6.)
3. Solar Constant - 442 BTU/Hr - (Mark's Mechanical Engineers Handbook, 6th Edition.)

Calculations:

$$\text{Required Exposure} = (30\text{ days})\ (24\text{ hrs/day})\ (442\text{ BTU/Hr})\ (0.0903)$$
$$\text{RE} = 28{,}737\text{ BTU/Ft}^2$$

$$\text{Fadeometer Exposure} = (240\text{ hrs})\ (33.9\text{ Watts/Ft}^2)\ (3.413\text{ BTU/Watt hr.})$$
$$\text{FE} = 27{,}768\text{ BTU/Ft}^2$$

$$\text{Fadeometer Exposure Equivalency} = \frac{27{,}768}{28{,}737}\ (30\text{ days}) = 28.99\text{ days.}$$

TABLE 4. NONREINFORCED POLYMER MATERIAL EVALUATION ELONGATION VS. TENSILE STRENGTH (psi) OF CANDIDATE POLYMERS (UNAGED, AGED 240 HRS./ULTRAVIOLET, AND AGED 1 WEEK AT 100°C.)

	Thickness Inches	Elongation 50%	100%	150%	200%	250%	300%	350%	400%	450%	500%	550%	600%	Break
<u>Ethylene/Propylene Copolymer</u>														
Unaged	0.074	–	270	–	475	–	860	–	–	–	–	–	–	1390
240 hrs./Ultraviolet	0.074	190	320	480	745	–	–	–	–	–	–	–	–	785
1 week at 100°C.	0.074	No Test – Samples reverted and tackified												
<u>Ethylene/Propylene Terpolymer</u>														
Unaged	0.065	–	200	–	325	–	530	–	855	–	–	–	–	1070
240 hrs./Ultraviolet	0.065	215	365	560	–	–	–	–	–	–	–	–	–	580
1 week at 100°C.	0.065	No Test – Samples cloudy and opaque												
<u>Urethane Polymer (Millable Polyester)</u>														
Unaged	0.050	–	570	–	750	–	1030	–	1530	–	2695	–	5655	5780
240 hrs./Ultraviolet	0.050	–	700	–	875	–	1095	–	1530	–	2475	–	3755	4855
1 week at 100°C.	0.050	–	605	–	855	–	1120	–	1465	–	2145	–	3410	4410
<u>Cpd #1 Dimethyl RTV Silicone</u>														
Unaged	0.065	110	615	–	–	–	–	–	–	–	–	–	–	750
240 hrs./Ultraviolet	0.065	110	560	–	–	–	–	–	–	–	–	–	–	860
1 week at 100°C.	0.065	160	625	–	–	–	–	–	–	–	–	–	–	755
<u>Cpd #2 Dimethyl RTV Silicone</u>														
Unaged	0.062	110	570	–	–	–	–	–	–	–	–	–	–	860
240 hrs./Ultraviolet	0.062	155	525	–	–	–	–	–	–	–	–	–	–	–
1 week at 100°C.	0.062	220	365	–	–	–	–	–	–	–	–	–	–	685
<u>Cpd #1 Polyisoprene Polymer</u>														
Unaged	0.060	85	140	–	–	–	–	–	–	–	–	–	–	–
240 hrs./Ultraviolet	0.060	60	–	–	–	–	–	–	–	–	–	–	–	65
1 week at 100°C.	0.060	No Test – Samples crazed and became opaque												
<u>Cpd #2 Polyisoprene Polymer</u>														
Unaged	0.063	75	110	–	–	–	–	–	–	–	–	–	–	120
240 hrs./Ultraviolet	0.063	45	–	–	–	–	–	–	–	–	–	–	–	65
1 week at 100°C.	0.063	No Test – Samples crazed and became opaque												

NOTE: All values are averages of three test samples with the exception of those exposed to ultraviolet light where only two values were obtainable from the exposed section.

TABLE 5. NONREINFORCED POLYMER MATERIAL EVALUATION GENERAL ELECTRIC RECORDING SPECTROPHOTOMETER % LIGHT TRANSMITTANCE – UNAGED

Polymer	Wave Length*						
	400 mμ	424 mμ	490 mμ	575 mμ	585 mμ	647 mμ	700 mμ
Ethylene Propylene Copolymer							
0.072" Thick Sheet	74%	79%	86%	88%	89%	89%	89%
0.145" Thick Sheet	58%	68%	79%	85%	85%	86%	87%
Ethylene Propylene Terpolymer							
0.064" Thick Sheet	65%	73%	82%	86%	86%	87%	88%
0.156" Thick Sheet	35%	49%	65%	75%	76%	79%	81%
Urethane Polymer (Millable Polyester)							
0.048" Thick Sheet	17%	65%	82%	84%	85%	88%	89%
0.072" Thick Sheet	5%	49%	75%	78%	79%	86%	86%
0.133" Thick Sheet	2%	35%	65%	71%	73%	83%	85%
Cpd #1 Dimethyl RTV Silicone							
0.037" Thick Sheet	92%	92%	94%	94%	94%	94%	94%
0.065" Thick Sheet	91%	92%	93%	94%	94%	94%	94%
0.155" Thick Sheet	91%	91%	93%	93%	93%	93%	93%
Cpd #2 Dimethyl RTV Silicone							
0.037" Thick Sheet	91%	92%	93%	94%	94%	94%	94%
0.075" Thick Sheet	89%	91%	93%	94%	94%	94%	94%
0.154" Thick Sheet	86%	88%	92%	93%	94%	94%	94%
Cpd #1 Polyisoprene Polymer							
0.055" Thick Sheet	61%	83%	87%	87%	87%	87%	87%
0.135" Thick Sheet	40%	72%	80%	82%	82%	82%	82%
Cpd #2 Polyisoprene Polymer							
0.044" Thick Sheet	68%	85%	89%	89%	89%	89%	89%
0.134" Thick Sheet	46%	80%	88%	88%	88%	88%	89%

*The entire visible spectrum range is encompassed between the 400 mμ to 700 mμ wave length limits tested. The respective wave length bands selected for tabulation in Tables 5, 6 and 7 cover the following continuous spectrum.

Wave Length Range** mμ	Color
400 - 424	Violet
424 - 490	Blue
490 - 575	Green
575 - 585	Yellow
585 - 647	Orange
647 - 700	Red

**Note: Maximum visibility in daylight or brilliant artificial light is at 556 mμ.

TABLE 6. NONREINFORCED POLYMER MATERIAL EVALUATION GENERAL ELECTRIC RECORDING SPECTROPHOTOMETER % LIGHT TRANSMITTANCE AFTER 1 WEEK AGING AT 100°C.

	400 mμ	424 mμ	490 mμ	575 mμ	585 mμ	647 mμ	700 mμ	Comments
Ethylene/Propylene Copolymer	No Test							Sample reverted/ tackified
Ethylene/Propylene Terpolymer	No Test							Sample became very cloudy & opaque
Urethane Polymer (Millable Polyester)								Sample changed from light to very dark amber/very slight crazing
0.052" Thick Sheet	7%	10%	52%	63%	65%	80%	84%	
0.078" Thick Sheet	2%	4%	44%	56%	58%	76%	81%	
0.136" Thick Sheet	1%	1%	30%	46%	49%	72%	79%	
Cpd #1 Dimethyl RTV Silicone								No alteration in clarity/ no crazing
0.037" Thick Sheet	87%	89%	92%	93%	93%	93%	93%	
0.060" Thick Sheet	85%	88%	92%	92%	92%	92%	92%	
0.171" Thick Sheet	75%	82%	90%	92%	92%	92%	92%	
Cpd #2 Dimethyl RTV Silicone								No alteration in clarity/ no crazing
0.038" Thick Sheet	89%	91%	92%	92%	92%	93%	93%	
0.082" Thick Sheet	86%	89%	92%	92%	92%	92%	92%	
0.126" Thick Sheet	83%	87%	91%	92%	92%	92%	92%	
Cpd #1 Polyisoprene Polymer	No Test							Samples crazed badly and became opaque
Cpd #2 Polyisoprene Polymer	No Test							

The "Recording Spectrophotometer" provides a curve which is a complete and exact specification. The instrument can be used where it is desired to measure color in the visible or near ultraviolet region of the spectrum.

Optical Quality Test

Initially an attempt was made to demonstrate optical quality of the polymers by superimposing the test sample of transparent material between a camera lens and a target to be photographed. Distortion was noted in the photographs which was greater than

TABLE 7. NONREINFORCED POLYMER MATERIAL EVALUATION GENERAL ELECTRIC RECORDING SPECTROPHOTOMETER % LIGHT TRANSMITTANCE AFTER 240 HOURS ULTRAVIOLET EXPOSURE

Polymer	Wave Length							Comments
	400 mμ	424 mμ	490 mμ	575 mμ	585 mμ	647 mμ	700 mμ	
Ethylene/Propylene Copolymer								
0.080" Thick Sheet	72%	78%	84%	87%	87%	88%	88%	No crazing
Ethylene/Propylene Terpolymer								
0.070" Thick Sheet	60%	69%	77%	81%	82%	83%	83%	No crazing
Urethane Polymer (Millable Polyester)								
0.073" Thick Sheet	5%	31%	72%	83%	84%	87%	87%	Slight crazing
Cpd #1 Dimethyl RTV Silicone Polymer								
0.066" Thick Sheet	86%	88%	92%	93%	93%	93%	93%	No crazing
Cpd #2 Dimethyl RTV Silicone Polymer								
0.076" Thick Sheet	84%	88%	91%	92%	92%	92%	92%	No crazing
Cpd #1 Polyisoprene Polymer								
0.062" Thick Sheet	52%	76%	84%	85%	85%	85%	85%	No crazing
Cpd #2 Polyisoprene Polymer								
0.067" Thick Sheet	55%	77%	86%	87%	87%	87%	87%	No crazing

that observed when viewing the object photographed through the sample with the naked eye. A pressure cell was devised which permitted the photographing of a target through the test sample while the sample was in a pressurized condition. This pressurization system worked well with filament reinforced samples but did not lend itself to use with non-reinforced polymeric sheets because of excessive blow-out. For purposes of our evaluation the naked eye was used, observing a calendar at a distance of approximately 20 feet, with the sample sheet held approximately 6" - 8" in front of the face. (See Table 8.)

TABLE 8. NONREINFORCED POLYMER MATERIAL EVALUATION VISUAL OPTICAL QUALITY TEST

Polymer	Comments		
	Unaged	Aged 7 Days Oven at 100°C	Aged 240 Hours Ultraviolet
Ethylene/Propylene Copolymer	Clear	Not Satisfactory Deteriorated	No change in clarity
Ethylene/Propylene Terpolymer	Clear	Cloudy	No change in clarity
Millable Polyester Urethane	Clear (light amber)	Clear (dark amber)	Slight crazing-cloudy
Compound #1 Dimethyl RTV Silicone	Clear	Clear	No change in clarity
Compound #2 Dimethyl RTV Silicone	Clear	Clear	No change in clarity
Compound #1 Polyisoprene	Clear (light amber)	Not Satisfactory Badly Crazed	No change in clarity
Compound #2 Polyisoprene	Clear (light amber)	Not Satisfactory Badly Crazed	No change in clarity

Permeability

Since we could not perform this test in-house, and found it necessary to submit the samples to an outside laboratory for evaluation, the permeability characteristics of the polymers were determined on only those polymers which successfully passed all other tests. (See Table 9.)

The test was performed in general in accordance with ASTM method D-1434-66. Dry test gas consisting of a mixture of 95% helium and 5% oxygen was introduced into the cell at the test pressure and the pressure was maintained four to sixteen hours prior to obtaining readings. Two specimens were tested for each sample and at least three determinations were made on each specimen. The data reported are average values. The gas was permeated through the specimen, collected in a capillary tube and the time to permeate a specific quantity of gas determined. Tests were performed at laboratory conditions of 23°C.

TABLE 9. GAS PERMEABILITY TEST – UNREINFORCED PANELS

Sample Identification		Gas Transmission* (cc/100 sq. in./24 hrs. at 23°C 1 atmosphere pressure) Thickness Inches	Unaged Sample	Thickness Inches	Aged Sample**
Cpd #1 Dimethyl RTV Silicone Unreinforced	A	0.071	3,656	0.061	5,026
	B	0.071	4,011	0.061	4,443
Millable Polyester Urethane Unreinforced	A	0.054	106.5	0.051	160.6
	B	0.054	112.6	0.051	128.2

*Area exposed in test 10.17 sq.in.
**1 week at 100°C

Flexibility Test

This test was performed using a "Bally Flexometer" manufactured by Bally's Shoe Factories, Ltd., Schndenenwerd, Switzerland.

(A) Instructions for use of Bally Flexometer

(1) The specimen, Figure 1-A is folded along its center line in the longitudinal direction, so that the side to be observed is turned inside. The specimen is clamped according to Figure 1-B into the clamp until the stop and the screw is tightened.

(2) The protruding part of the specimen is turned inside out downwards over the clamp, so that the bending edge runs vertically downwards. (See Figure 1-C.)

(3) The free end of the specimen is put without tension in the fixed clamp and the screw tightened. (See Figure 1-D.)

(4) The counter is put at zero by pressing down the lever in the motor. The apparatus provides 100 flexings a minute.

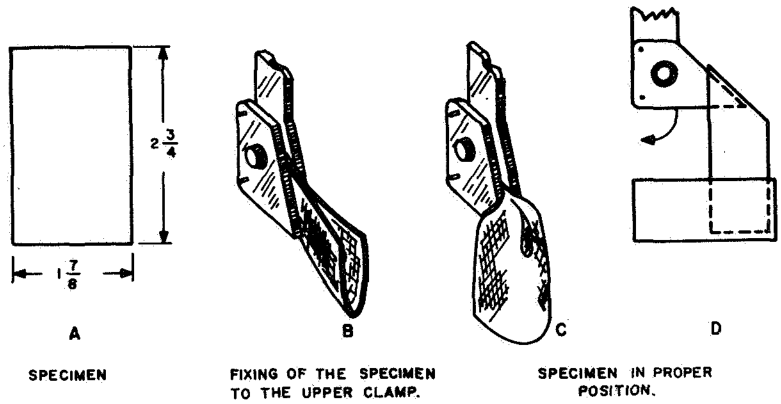

Figure 1. Bally Flex Testing Test

(B) Procedure

The specimen is controlled frequently during the first hour, afterwards only hourly.

(1) Examination of the finish:

After 1000 and 10,000 flexings the motor is stopped and the finish is observed for appearance of cracks.

(2) Examination of the sample itself:

The number of flexings until the sample breaks is determined.

The results of the Bally Flexing test performed on the seven polymers, identified in Table 2, are shown in Table 10.

All polymers except ethylene propylene copolymer and compound #2 polyisoprene showed excellent resistance against failure through flexing.

TABLE 10. BALLY FLEXING TEST–UNREINFORCED–UNAGED POLYMERS

Polymers	Panel Thickness, Inches	Number of Flex Cycles
Ethylene Propylene Copolymer	0.080	Cracked before test started.
Ethylene Propylene Terpolymer	0.070	349,000 - Test terminated at this point - no failure.
Polyester Urethane, Millable	0.073	349,000 - Test terminated at this point - no failure.
Cpd #1 Dimethyl RTV Silicone	0.066	349,000 - Test terminated at this point - no failure.
Cpd #2 Dimethyl RTV Silicone	0.076	308,000 - Cracked.
Cpd #1 Polyisoprene	0.062	233,000 - Test terminated at this point - no failure.
Cpd #2 Polyisoprene	0.067	Cracked before test started.

Aging Test Conditions

One Week Aging at 100° C

Test samples 6" x 6" were aged for one week at 100°C. in a circulating hot air oven. Samples were suspended in the oven, which was electrically heated, in order to assure uniform penetration of heat throughout.

Ultraviolet Radiation

Test samples were aged for 240 hours in accordance with ASTM procedure D-750-55T. Test samples 3" x 6" were placed in a fixture, in an unstrained condition, and exposed to the effect of light having essentially the same wave lengths as found in natural sunlight but with increased intensity in the ultraviolet range. Temperature, within the exposure unit utilized, was held at 68° ± 2°C. as measured utilizing black panel temperature.

SUMMARY OF POLYMER PHYSICAL CHARACTERISTICS

Ethylene Propylene Copolymer

The material had a tensile strength at break of 1400 p. s. i. and an elongation slightly in excess of 400%. At 100%, 200% and 300% elongation, the tensile strengths were 270 p. s. i., 475 p. s. i. and 860 p. s. i. respectively. Light transmission as measured, utilizing a General Electric Recording Spectrophotometer, in the visible spectrum band was found to be 74% to 89% at a thickness of 0.072" and 58% to 87% at 0.145" thick. The material did not withstand aging for one week at 100°C.; it became very tacky. After 240 hours exposure to ultraviolet light, the material exhibited a slight crazing. Due to a low modulus, and poor resistance to heat and ultraviolet exposure this material was eliminated from the study.

Ethylene Propylene Terpolymer

The material, which was clear amber shading toward a brown in color, exhibited a tensile strength at break of 1070 p. s. i. and an elongation of 400% to 500%. The tensile modulus of this polymer at 100%, 200%, 300% and 400% was 190 p. s. i., 325 p. s. i., 530 p. s. i. and 855 p. s. i. respectively. The light transmission qualities of an unaged test sheet 0.064" thick through the visible spectrum were 65% to 88% and 61% to 83% after 240 hours exposure to ultraviolet radiation. This material developed a milky or hazy translucency following one week of hot air exposure at 100°C. Due to the low modulus at 100% elongation as well as the deleterious effect of heat on the transparency of this material the ethylene propylene terpolymer was eliminated from the study.

Compound #1 Polyisoprene and Compound #2 Polyisoprene

These two polymers exhibited good light transmission qualities through the visible spectrum but their tensile and elongation characteristics were extremely low. Tensile strength was 100 p. s. i. to 140 p. s. i. and elongation 75% to 100%. After exposure to air at a temperature of 100°C. for one week the materials exhibited extreme crazing and embrittlement. Work on these isoprene polymers was discontinued as a result of the poor physical properties.

Millable Polyester Urethane

This material was an amber colored transparent polymer. The material was susceptible to moisture pick up in the uncured state and was molded at 177°C. minimum. Tensile strength and elongation of the unaged urethane at break were 5800 p. s. i. and 600% to 700%. The light transmission of an unaged sheet 0.072" thick through the visible spectrum was 5% to 86%. Although the color of the material deepened appreciably on aging for one week at 100°C. and showed a very slight crazing on exposure to ultraviolet radiation, the light transmission and physical properties were altered very little.

Compound #1 Dimethyl RTV Silicone

This material was selected for our major effort due to its excellent resistance to aging at 100°C. and to ultraviolet radiation. Although the tensile strength was less than desired, 750 p.s.i. at break with an elongation of 100% to 150%, the modulus was 615 p.s.i. at 100% elongation. The light transmission qualities of the silicone polymer were affected very little by aging.

Compound #2 Dimethyl RTV Silicone

There was very little difference between this polymer and compound #1 dimethyl RTV silicone insofar as the physical and light transmission characteristics were concerned. The compound #1 dimethyl RTV silicone showed slightly better retention of physical properties after exposure of one week @ 100°C. than did the compound #2 dimethyl RTV silicone. Although compound #1 RTV silicone was selected for further work in the study it was felt that compound #2 RTV silicone would be a satisfactory alternate.

POLYMERS SELECTED FOR CONTINUED EVALUATION

Based upon aging characteristics and light transmission qualities, compound #1 RTV silicone was selected as the primary polymer for continued evaluation in PHASES II and III of this study. Millable, polyester type polyurethane was selected as a secondary choice of polymer. Physical properties of compound #1 RTV silicone are maintained from -65°C. to 200°C.*

SELECTION OF REINFORCING SYSTEM FOR POLYMERIC MATERIAL

Three types of candidate reinforcing materials were investigated during the course of this study; the three types evaluated were glass, steel and synthetic. Eight glasses, one steel, and one polyester were evaluated.

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*From General Electric's brochure entitled "RTV-615 Clear Silicone Potting Compound."

TESTING OF REINFORCEMENT MATERIALS IN POLYMERIC MATRICES

Each reinforcement material was molded, (silicone matrix was cast), into test samples 5" x 1" x 0.060" as uniformily spaced unidirectional strands. The test samples were prepared in such a manner that the center 3" of the sample filament was embedded in compound #1 RTV silicone while 1" at each end was "potted" into epoxy or epoxy impregnated glass cloth. The filament ends were "potted" in the rigid epoxy resin in order to maximize the gripping of the filaments to prevent slippage during the tensile test. An effort was made to embed the samples in moldable, polyester polyurethane; this was unsuccessful, however, in that wrinkles and distortion occurred in the filaments during the molding operation. Acceptable samples were tested before and after aging for 1 week @ 100°C. All test specimens were evaluated as follows:

Surface Condition

As in the evaluation of polymeric materials this again was a visual observation only. All samples, with the exception of the polyester reinforced test piece, exhibited a smooth, uniform surface appearance. The polyester reinforced test sample was badly distorted and wrinkled after aging 1 week at 100°C. due to shrinkage of the reinforcing member.

Tensile Strength of Reinforcement Materials Embedded in Compound #1 RTV Silicone

This test was performed on the above described samples before and after aging 1 week at 100°C.

This test specimen was gripped at the epoxy resin reinforced ends in an Instron machine and tested at a jaw separation speed of 2 inches per minute. The results of the tensile strength tests performed on the respective reinforcement materials are shown in Table 11.

Reinforcement Adhesion

This test was performed, before and after aging 1 week at 100°C. by stripping the reinforcement from the matrix manually and examining the reinforcement under a microscope. Of all samples tested only G1 and G2 exhibited good adhesion as evidenced by particles of the matrix adhering to the filaments.

TABLE 11. TENSILE STRENGTH OF REINFORCEMENT MATERIALS EMBEDDED IN COMPOUND #1 RTV SILICONE MATRIX

Reinforcement (Finish and Type Glass)		Filament Size	Tensile Strength, Lb/End*	
			Unaged	Aged 1 Week at 100°C.
G1	901-S (1)	G	5.3	5.5
G2	1014-S (2)	G	4.9	5.3
G3	1026-E (3)	G	3.1	2.9
G4	801-E (4)	G	3.0	3.4
G5	902-E (5)	G	2.9	3.9
G6	810-E (6)	G	2.3	2.5
G7	711-E (7)	G	2.2	2.5
G8	1033-E (8)	G	1.3	0.7
P1	Polyester (9)	0.010" Dia.	6.9	No Test
S1**	Steel (10)	0.004" Dia.	6.3**	No Test

*One end of glass roving in this report consists of 204 G size filaments. A G size filament has a diameter of 0.00038 inch.

**This sample pulled out of the silicone and the epoxy, therefore sample was tested as a filament alone.

NOTE:

(1) HTS finish - Owens Corning Fiberglas Corp.

(2) HTS finish - Ferro Corp.

(3) Pittsburgh Plate Glass Co.

(4) Polyester/epoxy resin compatible finish - Owens Corning Fiberglas Corp.

(5) HTS finish - Owens Corning Fiberglas Corp.

(6) Airtron finish - Owens Corning Fiberglas Corp.

(7) Rubber compatible finish - Owens Corning Fiberglas Corp.

(8) Polyester/epoxy resin compatible finish - Pittsburgh Plate Glass Co.

(9) Polyester - Dupont Co.

(10) NS-355 wire - National Standard Co.

Selection of Reinforcement Material

The .010" diameter Dacron filament (polyester) had a tensile strength of approximately 6.9 pounds. Therefore to fulfill the 840 pounds tensile strength per inch width of window, required 122 filaments per inch in the girth direction. This amount of filaments would completely cover the entire surface of the window and therefore would not provide space between filaments for the clear matrix material. Also the Dacron filament showed excessive shrinkage after heat exposure. Optical properties of such a reinforced composite would be very poor. Dacron filaments were rejected for this reason. Based upon the ease with which the steel filaments separated from both the silicone matrix and the epoxy potting; and the strength of the glass filaments G1 as opposed to the polyester P1 filaments, a decision was made to continue this work utilizing G1 glass filaments and to make a best effort attempt to utilize steel wire, S1.

DESIGN OF REINFORCEMENT SYSTEM FOR FLEXIBLE WINDOW

The physical strength requirements for the flexible window system were determined to satisfy the end use parameters of withstanding an internal pressure of 35 p.s.i. in a flexible 48" diameter cylinder structure.

The specific strength requirement for both the circumferential and longitudinal (axial) direction were determined as follows:

Circumferential Strength

$$s_g = Pr \qquad (1)$$

where s_g = strength required in lbs. per inch of cylinder length.

P = internal pressure = 35 p.s.i.

r = radius of cylinder = 24 inches.

s_g = 35 (24) = 840 lbs.

Axial Strength

$$s_a = Pr/2 \qquad (2)$$

where s_a = strength required in lbs. per inch of circumference.

s_a = 35 (24)/2 = 420 lbs.

All of the reinforcement materials considered for this application developed a relatively low elongation at tension failure. Conversely, the elastomeric materials evaluated for the matrix developed substantial elongation under relatively low tension loads. Accordingly, the reinforcement materials essentially carried all of the load applied to the window structure when pressurized.

Reinforcement designs were established using judicious placement of the calculated reinforcement material requirement established using the design tensile strength parameters for the respective reinforcement materials shown in Table 12.

The reinforcement netting pattern design parameters established for the respective reinforcement materials are shown in Table 13.

Because of the difficulty of mathematically determining the optical deviation allowable without causing distortion, the parameters for acceptable facet radii between reinforcements were determined experimentally.

Preliminary inflation tests were performed on square shaped netting patterns featuring nonreinforced areas in unsupported widths (dimension "a") 0.01", 0.10", 0.25", 0.50", and 1.00". Each specimen was clamped in a cell and pressurized on one side with air. The pressure was then noted at which a visually detectable optical change occurred at the surface of the specimen. Equation #3 which is applicable to determining the maximum deflection of a square plate with fixed end edge conditions on all four sides during pressurization of one face, was then used to calculate the equivalent plate deflection.

$$\text{Max. Deflection} = \frac{0.0138\ wa^4}{Et^3} \qquad (3)^*$$

Where Maximum Deflection = Maximum Deflection of the plate - inches

w = Unit force on Plate – psi

a = Width of unsupported plate between reinforcements – inches

E = 100% Tensile Modulus of Elasticity of Matrix – psi

t = Plate thickness – inches

*Formulas for stress and strain, Raymond J. Roark, Third Edition, Equation 34, page 203.

TABLE 12. DESIGN TENSILE STRENGTH PARAMETER FOR REINFORCEMENT MATERIAL

Reinforcement Material	Tensile Strength–Lbs.
One end G1 glass roving (204 filaments)	6.0
One end S1 0.004" diameter monofilament steel	6.0
One end P1 0.010" diameter monofilament polyester	7.0

TABLE 13. REINFORCEMENT NETTING PATTERN DESIGN PARAMETERS FOR TRANSPARENT WINDOW REINFORCEMENT

Reinforcement Material	Reinforcement Direction	Number of Monofilaments or Ends Per Inch
S Fiberglass Roving - G1	Circumferential	140
S Fiberglass Roving - G1	Longitudinal (axial)	70
Steel 0.004" diameter - S1*	Circumferential	140
Steel 0.004" diameter - S1*	Longitudinal (axial)	70
Polyester 0.010" diameter - P1*	Circumferential	120
Polyester 0.010" diameter - P1*	Longitudinal (axial)	60

*Monofilament

The equivalent deflection radius was then calculated using Huygen's Approximation equation #4.

$$c = 2\sqrt{h(d-h)} \qquad (4)^*$$

Where c = Chord length of arc. C is referenced above as dimension "a" of the matrix design - inches

d = Diameter of Arc – inches

h = Maximum Distance Between Arc and Chord – inches

The calculated threshold radii which had shown first evidence of visual optical disturbance were then revised upward to the "assumed safe levels" shown in Table 14. The maximum radius selected corresponds with the curvature of the end use cylinder.

Several probable acceptable matrix design combinations were calculated. Typical design combinations are shown in Table 15.

Attempts to fabricate a composite reinforced transparent window using compound #1 RTV silicone in the two thicknesses of 0.030" and 0.060" respectively were unsuccessful due to incomplete coverage of the reinforcement filaments by the silicone matrix material. This condition seriously degraded the optical properties of the composite in the vicinity of inadequate filament coverage. Although the bottom sides of transparent windows which were molded against the 1/2 RMS finish mold plate, yielded surfaces with good optical properties with only a 0.015" - 0.025" thick film coverage over the reinforcement, this minimum film coverage could not be tolerated on the top side where no mold plate was used. The top side required a considerably greater thickness of cast material in order to avoid surface imperfections caused by "dishing" or "shrink-back" between reinforcements. Attempts to use a top mold plate were not successful because of entrapped air between the pre-cast silicone material and the top plate. This film thickness difference between the top and bottom side was present in all specimens prepared by casting. Continued trials showed that 0.125" thickness should be considered as the target minimum thickness when preparing the subject test specimens.

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*Mark's Mechanical Engineering Handbook

TABLE 14. ASSUMED PARAMETER TO OBTAIN A MINIMUM ACCEPTABLE LEVEL OF OPTICAL DISTORTION

Dimension "a"* Inches	Radius of Curvature** When Deflected, Inches	Deflection "H", Inches
0.01	6	2.1×10^{-6}
0.10	12	1.04×10^{-4}
0.25	24	3.25×10^{-4}
0.50	24	1.3×10^{-3}
1.00	24	1.04×10^{-2}

*Dimension "a" is width of unsupported matrix plate between filament reinforcements. See composite test specimen #1.

**Radius of unsupported matrix plate between filament reinforcements when deflected "H" inches.

TABLE 15. TYPICAL CALCULATED MATRIX DESIGNS

Matrix Thickness, Inches	Non-Reinforced Matrix Width "a", Inches (Max.)	Design Radius of Curvature at "a", Inches (Max.)	Design Deflection at "a", 1×10^{-6} (Max.)	Matrix Modulus of Elas. E, P.S.I. (Min.)
0.030	0.01	6	2.1	50
0.030	0.10	12	104.0	3390
0.030	0.25	24	325.0	10,000*
0.030	0.50	24	1300.0	10,000*
0.060	0.01	6	2.1	50
0.060	0.10	12	104.0	424
0.060	0.25	24	325.0	5360*
0.060	0.50	24	1300.0	10,000*
0.120	0.01	6	2.1	50
0.120	0.10	12	104.0	53
0.120	0.25	24	325.0	670
0.120	0.50	24	1300.0	2680

*Impractical modulus requirement for flexible matrix for thickness shown.

Accordingly, a target thickness of 0.125" was chosen for preparation of all reinforced transparent window constructions fabricated for testing.

The optical properties of all of the pressurized fabricated test panels were favored by the actual excess in specimen thickness. Although this parameter affected product weight, a high value for "t" appeared to have the following advantages:

(a) Resistance to matrix blow-out due to pressure was increased substantially.

(b) Window was less vulnerable to blow-out failure in the event of slight mechanical damage.

(c) Minimized optical discontinuities when pressurized by reducing degree of bulging.

(d) Decreased requirement for high modulus in the matrix.

However, should it be necessary to construct a window at the minimum of thickness, this could best be achieved by reducing the span "a" of the unsupported matrix.

Reducing the span of the unsupported matrix to achieve a thinner structure would have the advantage that the stress in the reinforcement filaments would be distributed over many filaments. The use of a large number of small filament bundles would decrease the thickness of such filament bundles. This reduction in filament reinforcement thickness would then reduce the matrix thickness required for good optical coverage of the filaments.

Five preliminary filament reinforced transparent window test specimens were prepared for initial screening tests as follows:

FILAMENT REINFORCED TRANSPARENT WINDOW
COMPOSITE TEST SPECIMEN #1

Composition	Design Specifications	Actual Specimen
Matrix		
Thickness	0.125"	0.151"
Composition		
Cpd #1-Dimethyl-RTV Silicone		
Modulus of Elas. E[1]	460 p.s.i. min.	615 p.s.i.** (260)[4]
Tensile Strength	300 p.s.i. min.	750 p.s.i.
Reinforcement*		
S-Glass Roving-Ends/Inch		
Circumferential	4-36[2]	4-40
Axial	4-20	4-20
Maximum Dimension "a"[3]	0.22"	0.22"
Composite Weight (Lbs./sq.ft.)	1.0 (maximum)	0.92

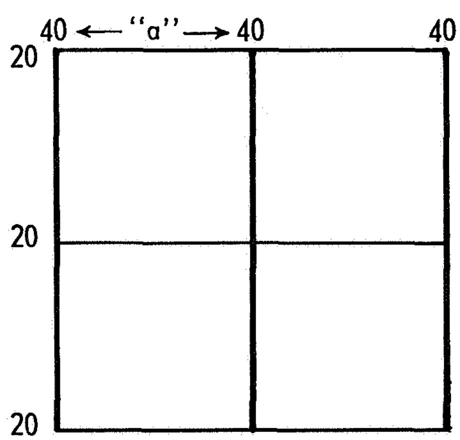
[1] 100% modulus

[2] Interpreted as four 36 end strands of S-glass roving.

[3] Maximum distance between groupings of strands of fiberglass reinforcement.

[4] Required for actual specimen (min.)

**Typical value.

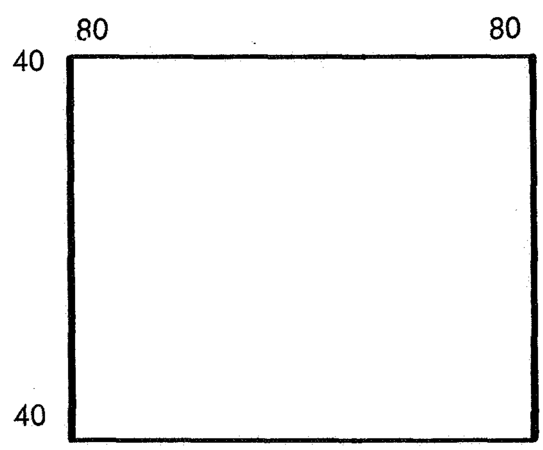


*Pattern #1

Scale 1" = 1/4"

FILAMENT REINFORCED TRANSPARENT WINDOW
COMPOSITE TEST SPECIMEN #2

Composition	Design Specifications	Actual Specimen
Matrix		
Thickness	0.125"	0.181"
Composition		
Cpd #1-Dimethyl-RTV Silicone		
Modulus of Elas. E	1920 p.s.i. min.	615 p.s.i. **(578)
Tensile Strength	300 p.s.i. min.	750 p.s.i.
Reinforcement*		
S-Glass Roving-Ends/Inch		
Circumferential	2-72	2-80
Axial	2-36	2-40
Maximum Dimension "a"	0.45"	0.43"
Composite Weight (Lbs./sq. ft.)	1.0 (maximum)	1.14
**Typical value		

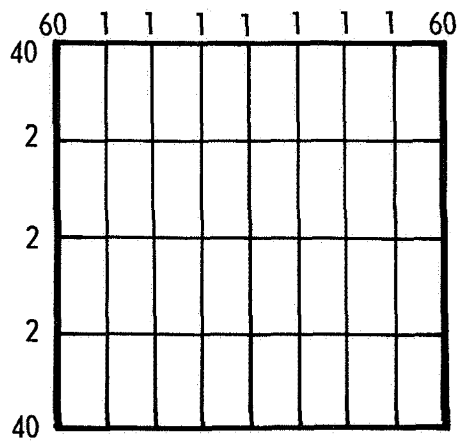


*Pattern #2

Scale 1" = 1/4"

FILAMENT REINFORCED TRANSPARENT WINDOW COMPOSITE TEST SPECIMEN #3

Composition	Design Specifications	Actual Specimen
Matrix		
Thickness	0.125"	0.194"
Composition		
Cpl #1-Dimethyl-RTV Silicone		
Modulus of Elas. E	42 p.s.i. min.	615 p.s.i.** (19)
Tensile Strength	300 p.s.i. min	750 p.s.i.
Reinforcement*		
S-Glass Roving-Ends/inch		
Circumferential	2-60	2-60
	16-1	14-1
Axial	2-30	2-40
	8-1	6-2
Maximum Dimension "a"	0.095"	0.119
Composite Weight (Lbs./sq.ft.)	1.0 (maximum)	1.24
**Typical Value		

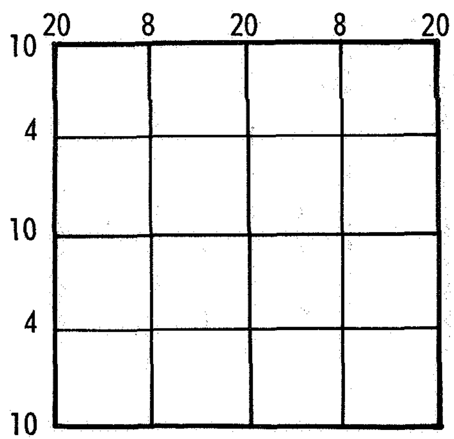


*Pattern #3

Scale 1" = 1/4"

FILAMENT REINFORCED TRANSPARENT WINDOW COMPOSITE TEST SPECIMEN #4

Composition	Design Specifications	Actual Specimen
Matrix		
Thickness	0.125"	0.160"
Composition		
Cpd#1-Dimethyl-RTV Silicone		
Modulus of Elas. E.	30 p.s.i. min.	615 p.s.i. ** (37)
Tensile Strength	300 p.s.i. min.	750 p.s.i.
Reinforcement*		
S-Glass Roving-Ends/Inch		
Circumferential	4-20	4-20
	8-8	4-8
Axial	4-10	4-10
	8-4	4-4
Maximum Dimension "a"	0.080"	0.130"
Composite Weight (Lbs./sq. ft.)	1.0 (maximum)	0.92
**Typical value		



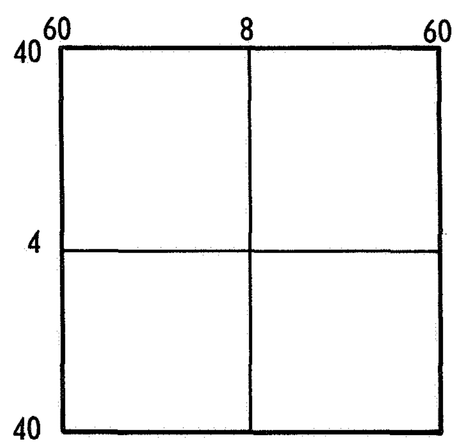
*Pattern #4

Scale 1" = 1/4"

FILAMENT REINFORCED TRANSPARENT WINDOW
COMPOSITE TEST SPECIMEN #5

Composition	Design Specifications	Actual Specimen
Matrix		
Thickness	0.125"	0.171"
Composition		
Cpd #1-Dimethyl-RTV Silicone		
Modulus of Elas. E.	460 p.s.i. min.	615 p.s.i. **(163)
Tensile Strength	300 p.s.i. min.	750 p.s.i.
Reinforcement*		
S-Glass Roving-Ends/Inch		
Circumferential	2-60	2-60
	2-8	2-8
Axial	2-30	2-40
	2-4	2-4
Maximum Dimension "a"	0.22"	0.21"
Composite Weight (Lbs./sq. ft.)	1.0 (maximum)	1.02

**Typical Value



*Pattern #5

Scale 1" = 1/4"

TESTING OF NETTING PATTERNS

Thickness and Weight

Each specimen representing the five netting patterns was weighed and gauged for thickness. (See Table 16.) All specimens were over the target thickness of 0.125". This higher thickness proved to be necessary to insure repetitive fabrication of blemish-free specimens.

Permeability

Gas permeability was determined on the aged (1 week at 100°C.) specimens in the same manner as on the unreinforced polymeric panels. (See Table 17.)

TABLE 16. FILAMENT REINFORCED TRANSPARENT WINDOW COMPOSITE TEST SPECIMENS #1 THRU #5 WEIGHT AND THICKNESS

Composite Test Specimen #	Weight Lbs./$Ft.^2$		Thickness, Inches	
	Design (Max.)	Actual Specimen	Design (Max.)	Actual Specimen
1	1.0	0.92	0.125	0.151
2	1.0	1.14	0.125	0.181
3	1.0	1.24	0.125	0.194
4	1.0	0.92	0.125	0.160
5	1.0	1.02	0.125	0.171

TABLE 17. FILAMENT REINFORCED TRANSPARENT WINDOW COMPOSITE TEST SPECIMENS #1 THRU #5 GAS PERMEABILITY TEST – UNAGED

Composite Test Specimen	Thickness Inches	Gas Transmission* cc/100 sq. in./24 hrs. @ 23°C 1 Atmosphere Pressure Difference
#1	0.151	1,072
#2	0.181	946
#3	0.194	1,855
#4	0.160	1,702
#5	0.171	670

*Area exposed in test 10.17 sq. in.

Flexibility

The thickness of the reinforced netting pattern specimens prohibited their flexing on the "Bally Flexometer" used in testing the non-reinforced polymer panels. As a consequence the samples were manually flexed 100 times, aged and unaged, through a full 180° bend. All samples satisfactorily passed this test with no evidence of cracking or fibers breaking away from the matrix being observed.

Light Transmission

Each netting pattern specimen was tested (before and after aging 1 week at 100°C.) for light transmission utilizing the G. E. Spectrophotometer. (See Table 18.)

TEST EVALUATION OF PRELIMINARY COMPOSITE TEST SPECIMENS

A very important test attribute of the composite transparent window structure being developed under this contract was its optical clarity as observed under simulated end use conditions. Therefore, visual observations were noted of the optical properties of the composite window structure under 0 p. s. i. and 7. 0 p. s. i. inflation pressure, before and after aging one week at 100°C. The specimens were pressurized in the 10 inch diameter fixture shown in Figure 2 and Figure 3.

The visual observation of optical properties is referred to in this report as the "Human Factors Optical Test."

Human Factors Optical Test

The developed human factors optical test for evaluation of optical clarity of filament reinforced windows involved noting the clarity of the characters of an eye chart (Figure 4) as observed through the test specimen window. The target eye chart was illuminated as noted in the respective tables of data and was positioned a definite distance beyond the test window. These observations were recorded at various distances of the eye to the test window as shown in the respective tables.

The human factors optical test rating plan was characterized as shown in Table 19.

The white numerical characters on the black background of the eye chart were classified as shown in Table 20.

The human factors optical test was performed on flat panels of the composite test specimen window structure not aged and aged, and under non-pressurized and pressurized conditions.

TABLE 18. FILAMENT REINFORCED TRANSPARENT WINDOW COMPOSITE TEST SPECIMENS #1 THRU #5

% LIGHT TRANSMITTANCE*

(Before and After Aging 1 Week at 100°C.)

Composite Test Specimen #	Wave Length						
	400 mμ	424 mμ	490 mμ	575 mμ	585 mμ	647 mμ	700 mμ
1. Unaged	70%	74%	75%	74%	74%	74%	74%
1. Aged	61%	64%	69%	72%	72%	73%	74%
2. Unaged	71%	73%	72%	71%	71%	71%	71%
2. Aged	58%	62%	67%	71%	71%	71%	71%
3. Unaged	73%	76%	80%	81%	81%	81%	81%
3. Aged	64%	68%	73%	77%	77%	78%	78%
4. Unaged	71%	72%	72%	71%	71%	71%	71%
4. Aged	66%	70%	73%	74%	74%	74%	74%
5. Unaged	58%	61%	63%	66%	66%	67%	68%
5. Aged	60%	64%	67%	70%	70%	70%	71%
5. Aged **							
Position #1	59%	61%	64%	66%	66%	67%	67%
Position #2	60%	63%	67%	70%	70%	71%	71%
Position #3	78%	81%	83%	83%	83%	82%	81%

*General Electric Recording Spectrophotometer

**These values included to show effect of altering position of test sample in holder. Values vary as the location of the netting (reinforcement) varies with respect to the photometer beam.

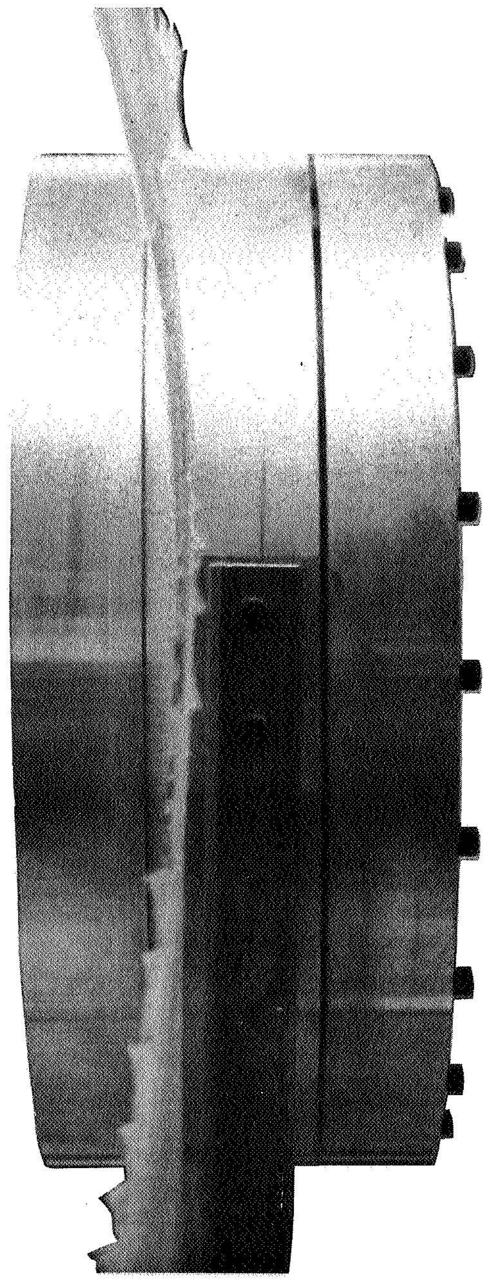


Figure 2. Side View 10" Diameter Pressure Fixture

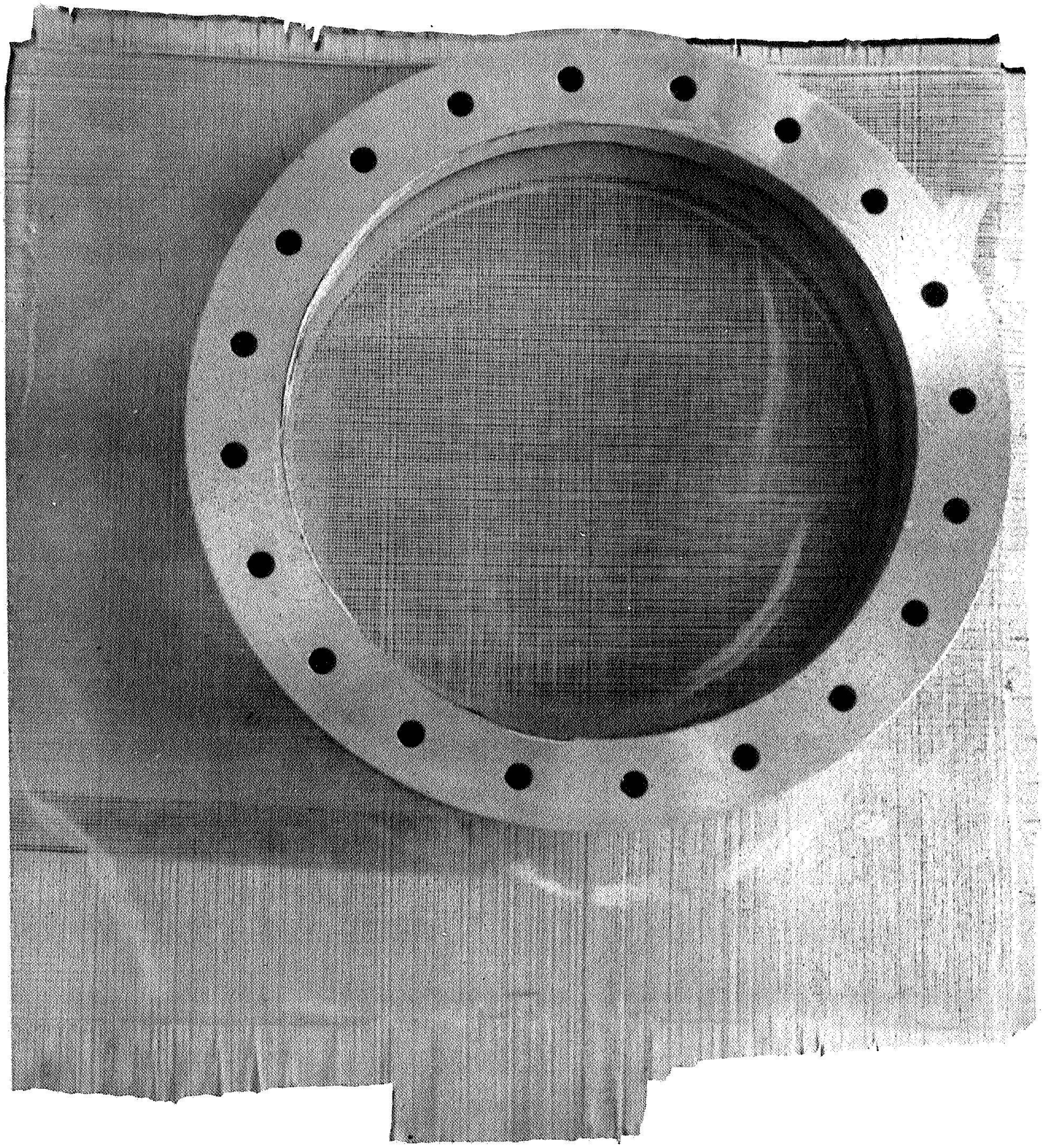


Figure 3. Pressurized Transparent Window as Viewed Through 10" Diameter Pressure Fixture

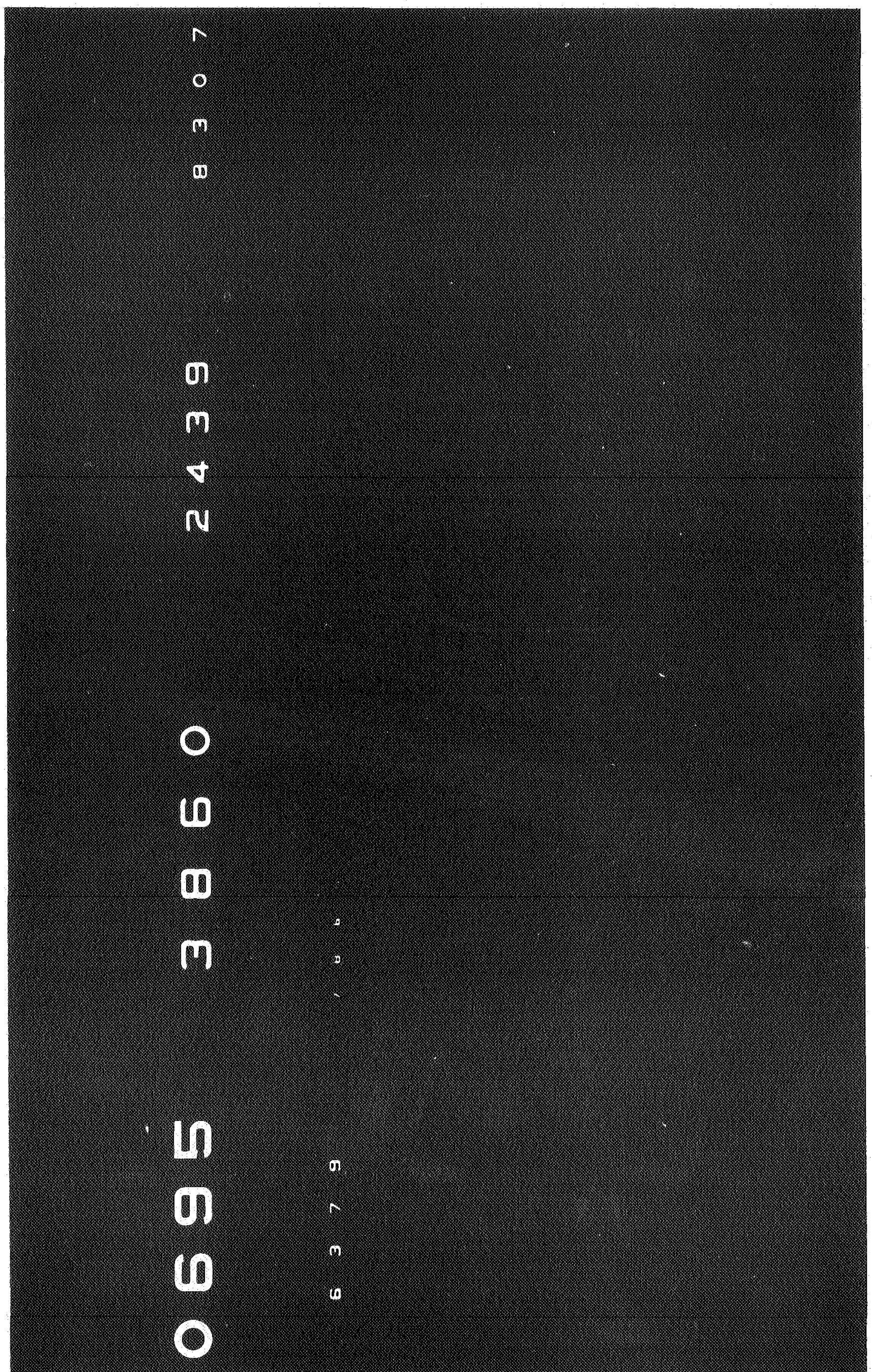


Figure 4. Human Factors Eye Chart

TABLE 19. HUMAN FACTORS OPTICAL TEST RATING PLAN

A. Blurriness (distortion).

B. Ability to focus.

C. Readability - (last clear number).

A. Blurriness (distortion).

1.* No distortion.

2.

3. Blurred but still comfortable.

4.

5. Highly distorted, uncomfortable.

B. Ability to Focus

1.* Eyes focus immediately.

2.

3. Strands change focus but still comfortable.

4.

5. Strands interfere with focusing.

C. Readability

1.* Reading clear - minimum of magnification disturbance.

2.

3. Letters change magnification but still comfortable.

4.

5. Reading moves with eye movement (high degree of magnification change).

Record last legible number.

*Equivalent to reference of no window present.

TABLE 20. CLASSIFICATION OF CHARACTERS ON HUMAN FACTORS OPTICAL EYE CHART

Number Sequence	Print Size (points)
0695	1/4 " 18 Points
3860	3/10" 14 Points
2439	5/32" 11 Points
8307	3/32" 6 Points

The results of the human factors optical test performed on panels of the preliminary selection of transparent window constructions (Composite Test specimens #1 through #5) are shown in Table 21.

TABLE 21. FILAMENT REINFORCED TRANSPARENT WINDOW COMPOSITE TEST SPECIMENS #1 THRU #5 HUMAN FACTORS OPTICAL TEST*

Composite Test Specimen No. 1

Human Factors Optical Test Parameter	Unpressurized Unaged	Pressurized 7.0 psi Unaged	Unpressurized Aged	Pressurized 7.0 psi Aged
Eye to Window 3"				
A.	3.3**	3.0	3.0	3.0
B.	2.7	3.5	2.7	3.5
C.	3.3	3.5	3.0	3.5
Last legible number	2439***	3860	8307	3860
Eye to Window 10"				
A.	4.0	---	---	---
B.	4.0	---	---	---
C.	4.0	---	---	---

* Target eye chart located 6 ft. beyond window. Target illumination - 45 ft. candles-incandescent, 15 ft. candles-reflective.
** Rating, see Table 19.
*** See Table 20 for print size.

TABLE 21. FILAMENT REINFORCED TRANSPARENT WINDOW COMPOSITE TEST SPECIMENS #1 THRU #5 HUMAN FACTORS OPTICAL TEST* (Continued)

Composite Test Specimen No. 2

Human Factors Optical Test Parameter	Unpressurized Unaged	Pressurized 7.0 psi Unaged	Unpressurized Aged	Pressurized 7.0 psi Aged
Eye to Window 3"				
A.	3.4	3.7	3.4	3.5
B.	3.4	4.0	3.4	4.0
C.	3.7	3.8	3.2	4.0
Last legible number	2439	2439	2439	0695
Eye to Window 10"				
A.	4.1	---	3.8	---
B.	4.4	---	3.8	---
C.	4.4	---	3.5	---
Last legible number	2439	---	2439	---

Composite Test Specimen No. 3

Eye to Window 3"				
A.	3.4	3.2	2.0	3.5
B.	3.0	3.0	2.0	3.5
C.	3.2	3.6	2.0	3.5
Last legible number	2439	2439	8307	0695
Eye to Window 10"				
A.	4.0	---	3.7	---
B.	4.2	---	3.7	---
C.	4.0	---	3.7	---
Last legible number	2439	---	2439	---

TABLE 21. FILAMENT REINFORCED TRANSPARENT WINDOW COMPOSITE TEST SPECIMENS #1 THRU #5 HUMAN FACTORS OPTICAL TEST* (Continued)

Composite Test Specimen No. 4

Human Factors Optical Test Parameter	Unpressurized Unaged	Pressurized 7.0 psi Unaged	Unpressurized Aged	Pressurized 7.0 psi Aged
Eye to Window 3"				
A.	3.0	2.0	3.5	2.0
B.	2.7	2.0	3.5	2.0
C.	3.6	2.0	4.0	2.0
Last legible number	2439	8307	2439	8307
Eye to Window 10"				
A.	3.8	---	4.0	---
B.	3.9	---	4.0	---
C.	4.0	---	4.0	---
Last legible number	2439	---	2439	---

Composite Test Specimen No. 5

Eye to Window 3"				
A.	3.0	3.1	3.2	3.4
B.	3.3	3.2	3.0	3.4
C.	3.3	3.4	3.4	3.4
Last legible number	2439	---	2439	3860
Eye to Window 10"				
A.	3.8	---	3.3	---
B.	4.0	---	3.4	---
C.	4.0	---	3.5	---
Last legible number	2439	---	2439	---

The final order of preference rating for the Composite test specimens, using all conditions in all tests was as follows:

Preference Rating	Composite Test Specimen Number
1	4
2	3
3	1 } Tie
4	5 } Tie
5	2

A review of the above analysis and previously completed materials evaulation tests with the National Aeronautics and Space Administration representative was concluded by designing ten filament reinforced transparent window constructions for fabrication and submission to NASA for their review prior to selecting optimum constructions for evaluation in Phase II.

FILAMENT REINFORCED TRANSPARENT WINDOW CONSTRUCTIONS SELECTED FOR REVIEW FOR USE IN PHASE II

Panel # Netting Pattern* and Matrix Material

1. **Girth direction – safety factor 5.0. (See Table 22.)**

   Four 27 end rovings** 1/4" spacing/inch.
   Four 8 end rovings equally spaced/inch.

   Axial direction – safety factor 5.2

   Four 14 end rovings 1/4" spacing/inch.
   Four 4 end rovings equally spaced/inch.

   Cpd #1 Dimethyl RTV silicone matrix

2. **Girth direction – safety factor 5.2.**

   Sixteen 9 end rovings equally spaced/inch.

---

*Netting patterns were based upon glass roving and 0.004" diameter steel wire strength of 6.0#/end.

**All rovings were S-901 glass.

Axial direction – safety factor 5.7.

Sixteen 5 end rovings equally spaced/inch.

Cpd #1 Dimethyl RTV silicone matrix

3. Girth direction – safety factor 3.0.

Four 15 end rovings 1/4" spacing/inch.
Four 6 end rovings equally spaced/inch.

Axial direction – safety factor 3.1.

Four 8 end rovings 1/4" spacing/inch.
Four 3 end rovings equally spaced/inch.

Cpd #1 Dimethyl RTV silicone matrix

4. Girth direction – safety factor 3.4.

Sixteen 6 end rovings equally spaced/inch.

Axial direction – safety factor 3.4.

Sixteen 3 end rovings equally spaced/inch.

Cpd #1 Dimethyl RTV silicone matrix

5. Girth direction – safety factor 5.2.

Two 65 end rovings 1/2" spacing/inch.
Fourteen 1 end rovings equally spaced/inch.

Axial direction – safety factor 5.1

Two 32 end rovings 1/2" spacing/inch.
Six 1 end rovings equally spaced/inch.

Millable polyurethane elastomer matrix

6. **Girth direction – safety factor 5.2.**

Two 65 end rovings 1/2" spacing/inch.
Fourteen 1 end rovings equally spaced/inch.

Axial direction – safety factor 5.1.

Two 32 end rovings 1/2" spacing/inch.
Six 1 end rovings equally spaced/inch.

Cpd #1 Dimethyl RTV silicone matrix

7. **Girth direction – safety factor 3.1.**

Two 40 end rovings 1/2" spacing/inch.
Six 1 end rovings equally spaced/inch.

Axial direction – safety factor 3.1.

Two 20 end rovings 1/2" spacing/inch.
Four 1 end rovings equally spaced/inch.

Cpd #1 Dimethyl RTV silicone matrix

8. **Girth direction – safety factor 4.9.**

Two 60 ends 0.004" diameter steel wire 1/2" spacing/inch.
Two 8 ends 0.004" diameter steel wire 1/4" spacing/inch.

Axial direction – safety factor 6.3.

Two 40 ends 0.004" diameter steel wire 1/2" spacing/inch.
Two 4 ends 0.004" diameter steel wire 1/4" spacing/inch.

Cpd #1 Dimethyl RTV silicone matrix

9. **Girth direction – safety factor 6.3**

Two 80 end rovings 1/2" spacing/inch.

Axial direction – safety factor 6.3.

Two 40 end rovings 1/2" spacing/inch.

Cpd #1 Dimethyl RTV silicone matrix

10. **Girth direction – safety factor 5.0.**

Four 35 end rovings 1/4" spacing/inch.

Axial direction – safety factor 5.2.

Four 18 end rovings 1/4" spacing/inch.

Millable polyurethane elastomer matrix

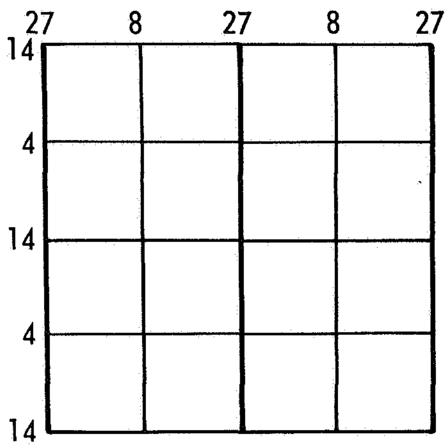
A graphic presentation of the ten selected window constructions are shown in Table 22.

NASA Langley produced some excellent photographic records of the optical qualities of the polymers evaluated utilizing unpressurized non-reinforced and unpressurized reinforced test sheets of the candidate polymers supplied to them in partial fulfillment of this contract. (See figures 5A thru 5K.)

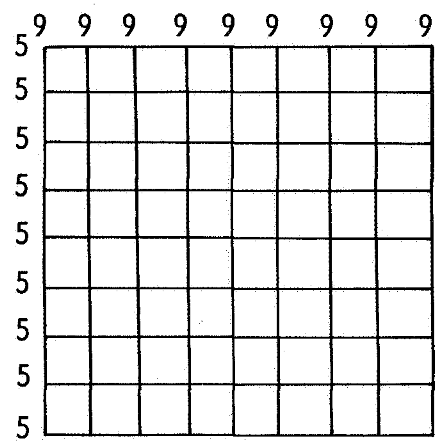
Refer to, "Filament Reinforced Transparent Window Constructions selected for review for use in Phase II" pages 45-51 and Table 22 for design details.

Review of the ten patterns listed above led to the selection of design/constructions Panel #1, #4, and #8 for continued evaluation in PHASE II.

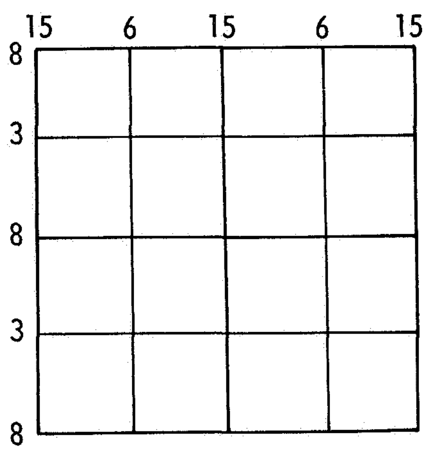
TABLE 22. FILAMENT REINFORCED TRANSPARENT WINDOW CONSTRUCTIONS SELECTED FOR REVIEW FOR USE IN PHASE II



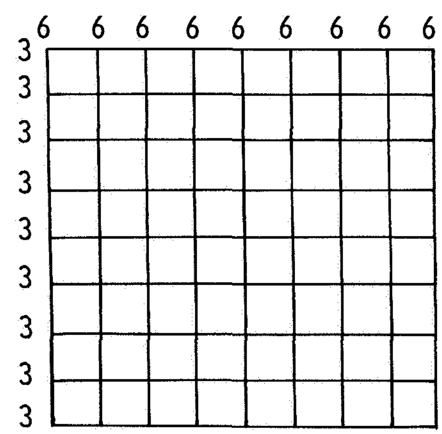
DESIGN #1



DESIGN #2



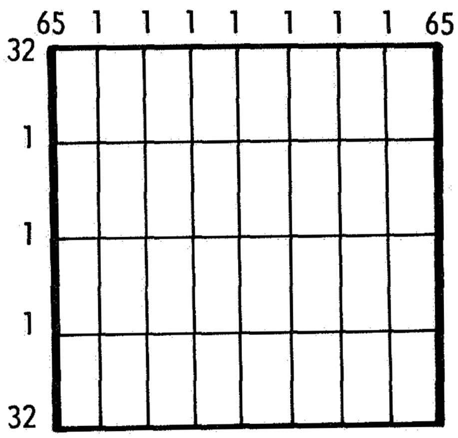
DESIGN #3



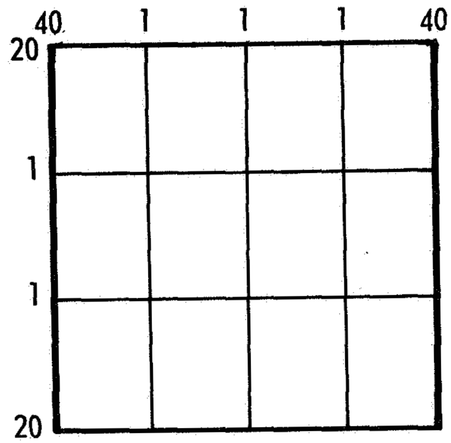
DESIGN #4

SCALE 1" = 1/4"

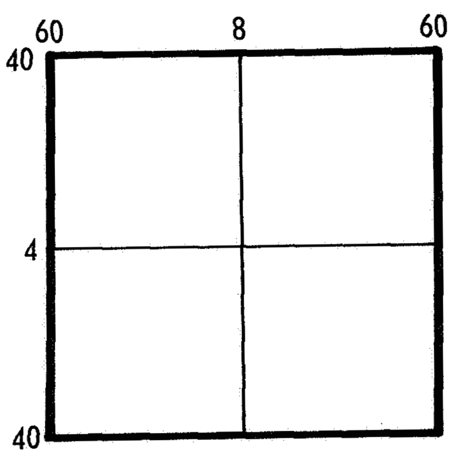
TABLE 22. FILAMENT REINFORCED TRANSPARENT WINDOW CONSTRUCTIONS SELECTED FOR REVIEW FOR USE IN PHASE II (Continued)



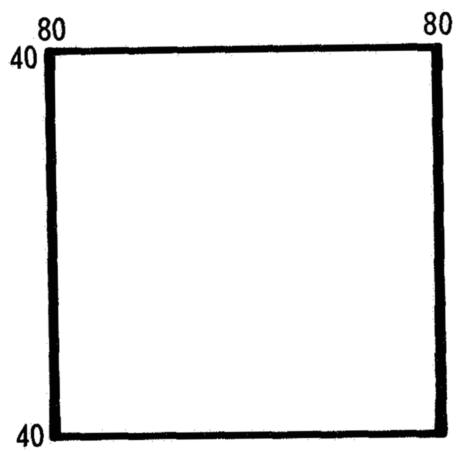
DESIGNS #5 AND #6



DESIGN #7



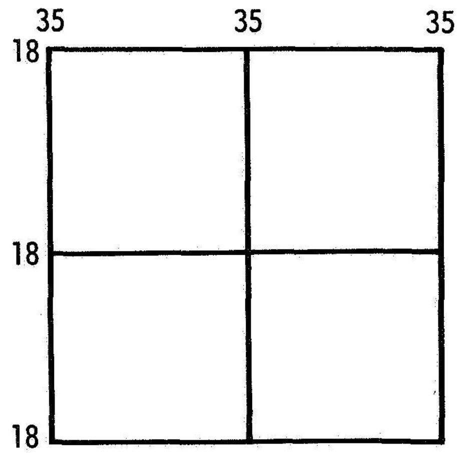
DESIGN #8



DESIGN #9

SCALE 1" = 1/4"

TABLE 22. FILAMENT REINFORCED TRANSPARENT WINDOW CONSTRUCTIONS SELECTED FOR REVIEW FOR USE IN PHASE II (Continued)



DESIGN #10

SCALE 1" = 1/4"

Figure 5A. Reinforced Panel Series – Clear

Figure 5B. Reinforced Panel Series – Dimethyl RTV Silicone – Design #1

Figure 5C. Reinforced Panel Series – Dimethyl RTV Silicone – Design #2

Figure 5D. Reinforced Panel Series – Dimethyl RTV Silicone – Design #3

Figure 5E. Reinforced Panel Series – Dimethyl RTV Silicone – Design #4

Figure 5F. Reinforced Panel Series – Millable Polyester Urethane – Design #5

Figure 5G. Reinforced Panel Series – Dimethyl RTV Silicone – Design #6

Figure 5H. Reinforced Panel Series – Dimethyl RTV Silicone – Design #7

Figure 5I. Reinforced Panel Series – Dimethyl RTV Silicone – Design #8

Figure 5J. Reinforced Panel Series – Dimethyl RTV Silicone – Design #9

Figure 5K. Reinforced Panel Series – Millable Polyester Urethane – Design #10

PHASE II

FLAT SHEET AND CYLINDRICAL SECTION ATTACHMENT DESIGN

DESIGN PARAMETERS

The attachment system was designed to retain the transparent window structure integral with the 48" diameter flexible structure wall system while stressed under 35 p.s.i. internal pressure.

The stress developed at the edge of the window when subjected to the normal stresses of the flexible 48" diameter cylindrical section, was 840 pounds per inch of cylindrical length and 420 pounds per inch of axial length. Therefore, the window attachment system had to withstand a "pull-out" load of 840 pounds per inch and 420 pounds per inch respectively for the two principle axes.

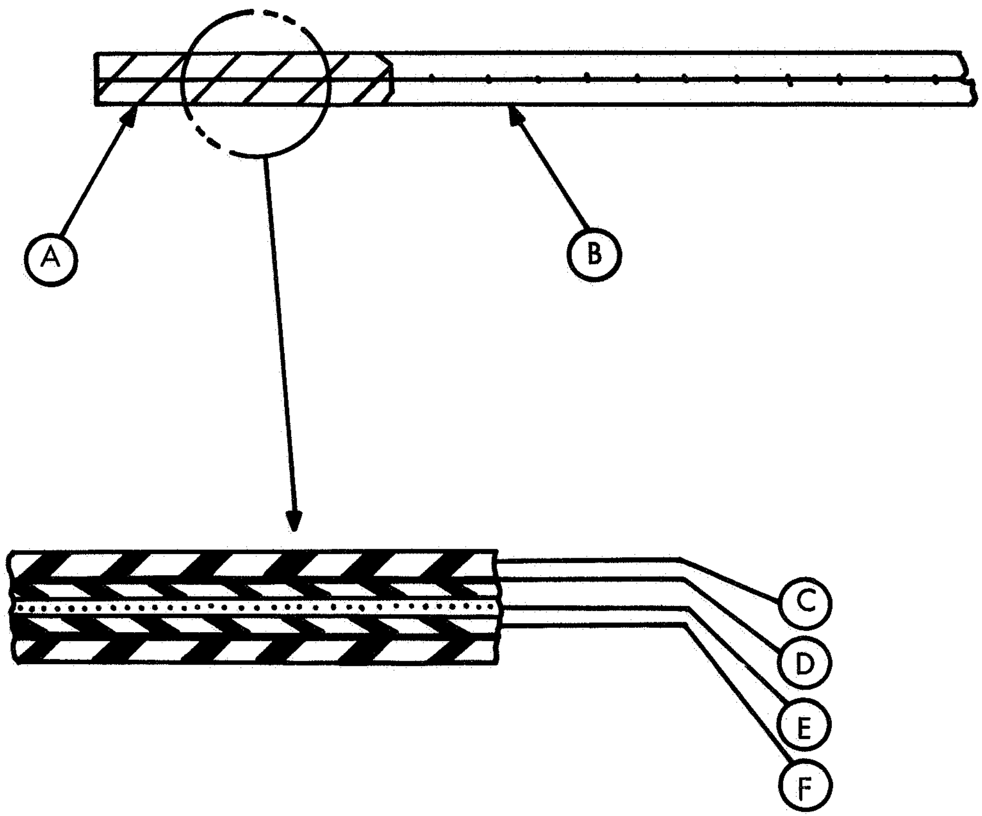
ATTACHMENT CONCEPTS

Two methods were evaluated for attaching sections of the flexible transparent constructions selected from Phase I to an expandable structure. The methods evaluated were adhesive bonding and mechanical clamping. Also determined, was a method of framing the flexible composite structure so that it might be incorporated into a flexible space structure.

Adhesive Methods

Inasmuch as the principle stresses of the transparent composites were carried by the reinforcement filaments, the attachment problem revolved around developing the necessary bonding of the reinforcement filaments around the periphery of the window to meet the "pull out" requirements.

Preliminary tests showed glass roving strands, embedded in Compound #1 dimethyl RTV silicone matrix, developed very low values for "pull out" strength; therefore bonding the window to the flexible wall structure directly through the silicone matrix was not practical. Embedding the reinforcement filaments in a nitrile type polymer developed the necessary filament anchorage for attachment to the flexible wall structure. (See Figure 6.) It was found that a minimum of two inches of bond area along the respective reinforcement filaments was required to develop maximum



LEGEND

(A) NITRILE ANCHORAGE FLANGE.

(B) SILICONE MATRIX WITH FIBERGLASS REINFORCEMENT.

(C) CURED NITRILE RUBBER .

(D) NITRILE CEMENT.

(E) FIBERGLASS REINFORCEMENT.

(F) UNCURED NITRILE RUBBER.

Figure 6. Cross Section of Flexible Transparent Window Showing Nitrile Polymer Anchorage for Reinforcement Filaments

strength in the anchored filaments. Various adhesive systems were evaluated for adhesively bonding the glass roving to a nitrile type polymer. Table 23 presents the adhesives evaluated with the results obtained:

TABLE 23. 901S – GLASS ROVING ADHESION VS. BONDING SYSTEM
(Rovings Bonded into Nitrile Flange)

Adhesive	Lbs. Pull/20 End Glass Roving
Nitrile Polymer Based	101.6*
Epoxy Resin/NMA[1]/BDMA[2]	8.9
Epoxy Resin (3 part system)	45.0
Epoxy Resin/ZZL-0820[3]	35.9
Epoxy Resin/NMA/BDMA	20.5
Epoxy Resin/BF-400[4]	32.4
Ty Ply BN/Nitrile Adhesive	42.8
No Treatment	34.0

[1]Nadic Methyl Anhydride
[2]Benzyl Dimethylamine
[3]Proprietary
[4]Boron Trifluoride

*This adhesive system chosen for continued evaluation and use in Phase II and Phase III work plans.

DESIGN OF ADHESIVE SYSTEM FOR ATTACHMENT OF TRANSPARENT WINDOW TO A FLEXIBLE WALL STRUCTURE

An ellipse whose major axis was 11.4" and minor axis 8.0" was chosen for the window opening. A nitrile type polymer filament anchorage band approximately 2.0" wide was thoroughly bonded to the reinforcement filaments beyond the basic window dimensions noted above. Two "doilies" wound to the ellipse shape and two inches wide were then adhered to both faces of the nitrile polymer anchorage band. These doilies contained sufficient filament strength to permit transferring the developed circumferential and axial stresses around the window structure.

The number of glass ends required in the respective reinforcement doilies was calculated as follows:

$$\text{Circumferential Stress} = Pr = 35\,(24) = 840 \text{ lbs./inch} \qquad (5)$$

$$Fr = sg\,(Rp) \qquad (6)^*$$

where Fr = force developed in the reinforcing doilies per axial width of doily

Rp = radius of window plus ½ width of reinforcement doily

$$Fr = 840\,(4.0 + 1.0) = 4200 \text{ lbs.}$$

$$e_r = \frac{4200}{2\,(5.0)} = 420 \text{ ends}$$

e_r = ends of glass at 5.0 lbs./end in doily (min.)

The stress was transferred from the window reinforcement system through the 2" wide anchorage band. The anchorage band then transferred this load to the walls of the test chamber. Therefore, good adhesion between the anchorage system and the flexible wall was of paramount importance.

In the subject design, two doilies of 600 ends each were used to transfer the stress potential of 840 lbs. per linear inch to the flexible wall structure. Through use of these two doilies 2" wide, the adhesion requirement was reduced to 210 lbs./inch. A tensile strength of 6000 lbs/inch was developed, equivalent to a safety factor of 1.4.

The "doilies" were wound using an ellipsoidal winding jig and single end roving. The roving was passed through the nitrile type polymer adhesive system integral with the winding operation.

A series of adhesives and adhesive combinations was also evaluated as bonding agents between the cured silicone matrix of the transparent composite and the cured nitrile components of the window as fabricated for "lay up" in the test panels. This was a purely empirical evaluation based upon observation of the joined surface after a "hand peel" test.

Seventeen adhesives or adhesive combinations were evaluated. The optimum results were obtained, based upon tearing of the silicone surface. A combination of a silicone adhesive A-4000 and an epoxy based adhesive 943 was chosen as the best adhesive for continued evaluation and use in Phase II and Phase III work plans.

Fabrication of Flexible Transparent Window

The transparent Window Attachment Assembly was initially constructed as shown in Figure 7A.

*Uniroyal U.S. Rubber Co. Design Note EF-RC-225

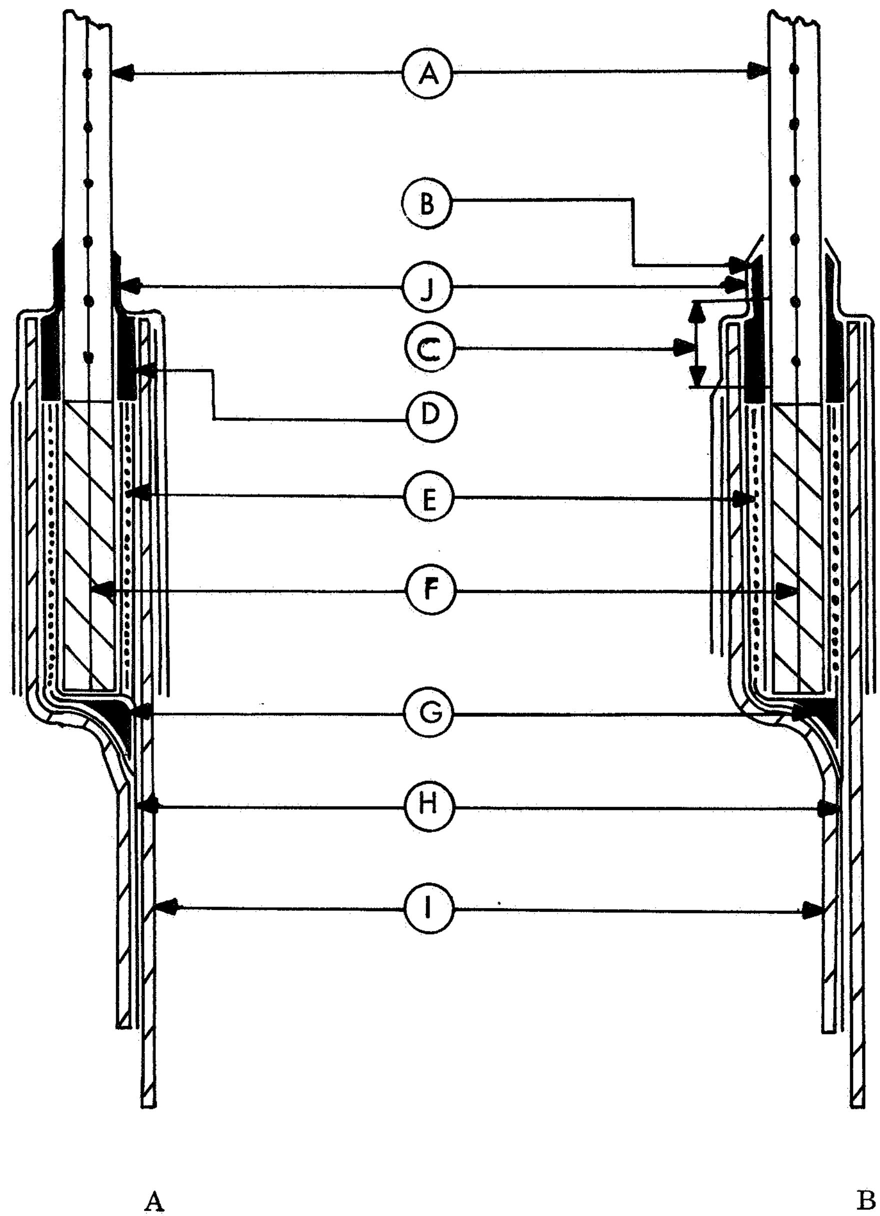


Figure 7. Schematic A, B, Cross Section of Transparent Window in Flexible Glass Cloth Panel

LEGEND OF CROSS SECTION OF TRANSPARENT WINDOW IN FLEXIBLE GLASS CLOTH PANEL (FIGURES 7A AND 7B)

(A) - Silicone window with fiberglass reinforcement.

(B) - Silicone adhesive A-4000/epoxy 943 adhesive system at silicone/nitrile interface.

(C) - Non-adhesion area of cured nitrile polymer sealant--pressure side only.

(D) - Silicone adhesive 607 used at silicone/nitrile interface.

(E) - Fiberglass doily embedded in uncured nitrile rubber.

(F) - Cured nitrile anchorage flange.

(G) - Uncured nitrile rubber.

(H) - Nitrile cement.

(I) - Flexible fiberglass cloth.

(J) - Nitrile rubber seal.

Fabrication of Nitrile Anchorage Flange for Glass Roving Reinforcement

Preparation of Nitrile Flange

(A) Two 16" x 16" sheets of nitrile rubber were molded and semi-cured.

(B) The centers of the sheets were located and templates were used to mark the exact area and location of the flange.

(C) The flange area was buffed, cleaned, degreased, and a brush coat of nitrile cement applied to the buffed area.

(D) Templates were placed in the area where there was to be no adhesion.

(E) A strip of uncured nitrile rubber was applied to the cemented oval areas of the nitrile sheets to assure better anchorage of the glass roving in the flange.

Assembly of Nitrile Flanges on the Glass Roving Reinforcement Netting Pattern

(A) One of the 16" x 16" nitrile sheets was placed under the reinforcement netting pattern, previously "woven", on the frame/mold tooling. (See Figure 8.)

(B) The glass roving was coated with nitrile cement in the oval area restricted by the templates. (See Figure 9.)

(C) The second 16" x 16" nitrile sheet (previously cemented and stripped with uncured nitrile rubber was placed on top of the other nitrile sheet with the fiberglass roving being embedded between the two sheets. The sheets were firmly "rolled" together in the area to be adhered. (See Figure 10.)

(D) The frame/mold tooling was then placed in a press and the window was cured one hour at 154° C. and 100 p.s.i. pressure.

Casting of the Compound No. 1 Dimethyl RTV Silicone

(A) After the window was removed from the press, templates were used to relocate the adhesion areas on the nitrile sheets.

(B) The center oval area (which eventually became the transparent portion of the window) was carefully cut out and removed on both sides of the fiberglass roving.

(C) The window remained on the frame and the bottom of the mold (a chrome plate with 1/2 RMS finish) was heated to 66°C. to help accelerate the cure of the dimethyl RTV silicone.

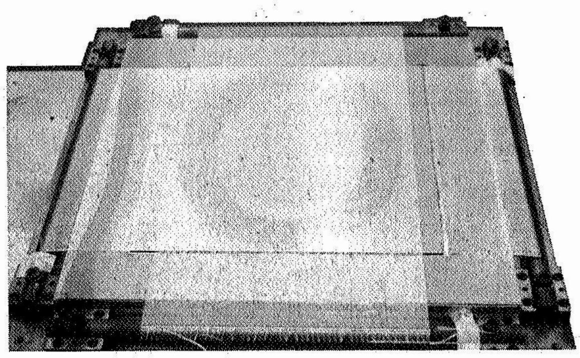


Figure 8. Precemented Nitrile Flange Material Beneath Netting Pattern

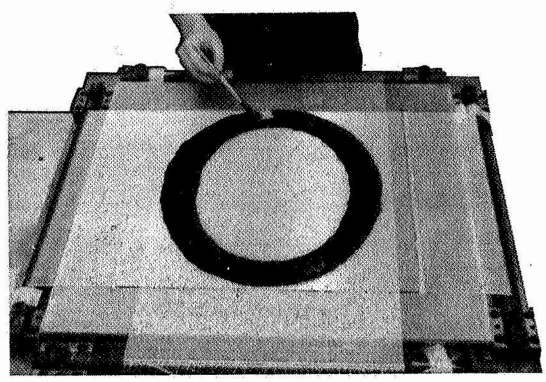


Figure 9. Application of Nitrile Cement to Fiberglass and Nitrile Flange Material

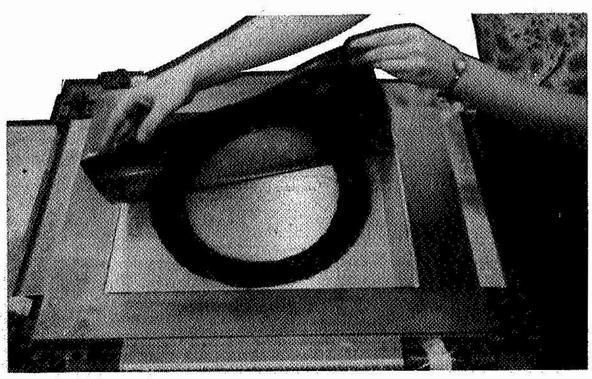


Figure 10. Precemented Nitrile Flange Material Being Placed Over Cemented Fiberglass Reinforcements

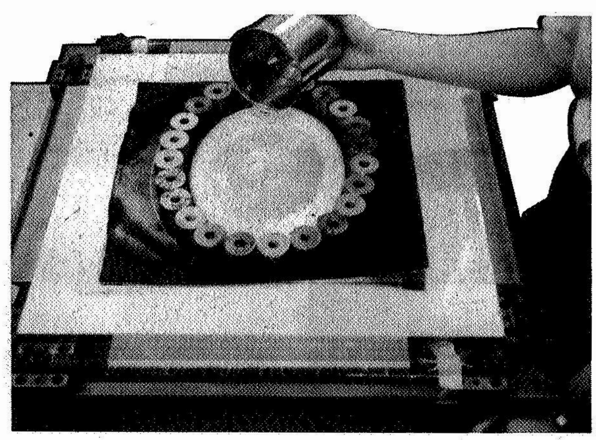


Figure 11. Casting of Silicone Polymer

(D) The dimethyl RTV silicone was mixed and vacuumed to remove all entrapped air. The silicone was then slowly cast in the oval section of the window. (See Figure 11.) After casting, the window section was covered with a polyethylene sheeting to prevent dirt contamination. The silicone was allowed to cure at room temperature for 12-16 hours.

(E) At this point, the nitrile flange was trimmed and the roving was cut from the frame and tied around the outside periphery of the nitrile flange. (See Figures 12 & 13.) The knots were brushed with a nitrile cement.

(F) The window was carefully removed from the chrome plate and placed in a 70°C. electric oven for two hours to complete the cure of the silicone and the nitrile cement. (See Figure 14.)

Application of Nitrile Seal Over Flange/Silicone Butt Joint

(A) Two 0.015" thick sheets of nitrile compound were molded in a press for 15 minutes at 154°C.

(B) Templates were used to mark the adhesion and non-adhesion areas desired.

(C) The template areas were buffed, cleaned, degreased, and brush coated with nitrile cement. A Mylar ring was placed in the areas where non-adhesion was desired.

(D) The transparent window (flange and a narrow band of the silicone) was buffed, cleaned and degreased. The nitrile portion of the window flange was brush coated with nitrile cement. The silicone portion of the window was primed with a silicone adhesive (A-4000) and then given a coating of a flexible epoxy adhesive (943).

(E) The nitrile seals were carefully placed on each side of the transparent window. The window was heavily weighted between two plates and the adhesives allowed to "room-temperature cure" for 12-16 hours.

The window now was ready to be assembled into a panel composite, a mechanical clamping device, or a S/M-1 filament-wound chamber.

Some difficulty was initially experienced in the casting of the silicone matrix due to the apparent "poisoning" of the silicone in the immediate area of the nitrile flange, as indicated by failure of the silicone to cure. This condition was minimized by the introduction of Step C in the procedure for Casting of the Compound #1 RTV silicone matrix. Future work on transparent composites, using the concepts covered in this report, should consider the use of nitrile flanges containing additives which are not detrimental to the cure of the silicone.

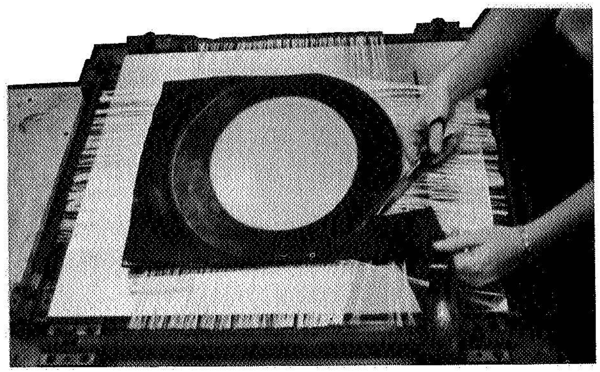


Figure 12. Trimming of Excess Nitrile Flange Material from Window of Transparent Cured Silicone

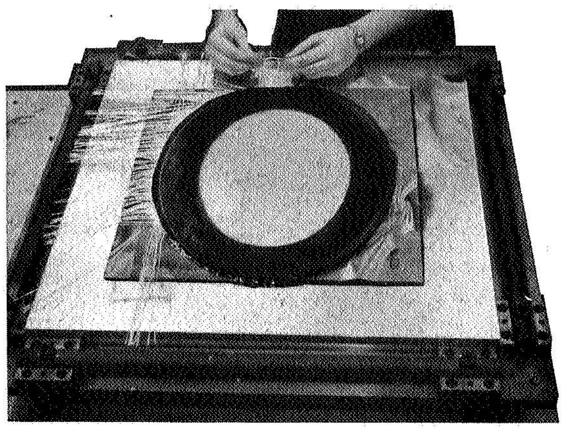


Figure 13. Tying of Fiberglass Reinforcement

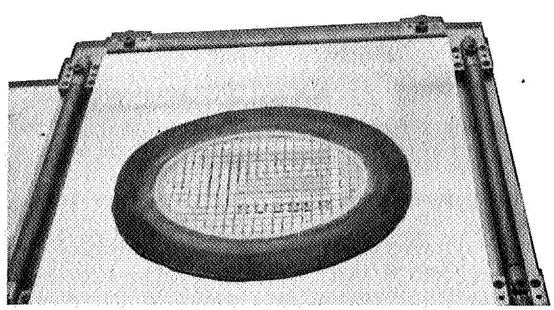


Figure 14. Completed Flexible Transparent Window After Final Cure of Silicone and Nitrile Cement

In preliminary inflation tests it was noted that the 0.015" thick nitrile polymer seal (Figure 7A item J) developed a high stress concentration at the attachment point along the inside periphery of the window. This premature failure was apparently due to the low inherent strength of the silicone matrix which cracked or "cleaved" locally under the developed high strains. This localized failure was minimized by incorporating an "unbonded" area between the window and the anchorage system for the window. This change in construction is shown as item C in Figure 7-B. Final changes to assure non-adhesion in the seal area by incorporation of a Mylar ring are shown as items I and J in Figures 15-A and 15-B respectively. The construction shown in Figure 15-B was used in fabrication of panels for the remainder of Phases II and III, starting with panel 7 as shown in Table 24.

MECHANICAL ATTACHMENT METHODS

Mechanical Methods

Three jigs representing three mechanical attachment methods were evaluated. Two of the attachment types were designed to simulate components of a flexible (segmented) clamping concept while the third type represented a solid, inflexible clamping method. The flexible clamping jigs were designed to clamp upon the wall structure and overlap and clamp upon the transparent composite matrix. The silicone matrix was unable to withstand the crushing load imposed upon it by the clamps.

Midway in the course of this study, a meeting was held with the representative of the National Aeronautics and Space Administration monitoring contract NASI-5524. A decision was made that a solid ring fitting as opposed to a segmented ring fitting would be satisfactory for a mechanical clamping method. Utilizing an inside and outside contoured clamp, the transparent composite window was bolted, through a reinforced frame directly to the structure to which it was affixed (see figure 16).

FABRICATION OF TEST PANELS FOR PRESSURE TESTING

Flexible test panels were fabricated as shown in Figures 17 and 18. The adhesively bonded window specimens were assembled to yield a joint profile around the transparent window opening. The mechanically bonded window was clamped to a flexible test panel, (Figure 19), and the window and panel were joined together with the aid of an inside and outside contoured clamp. (See Figure 16.) The respective windows were then evaluated by the human factors test before and after pressurization to 7.0 p.s.i. and after subjecting the test window to 7.0 p.s.i. pressure for 24 hours, (see Figures 20 and 21). The results of these tests are shown in Table 24.

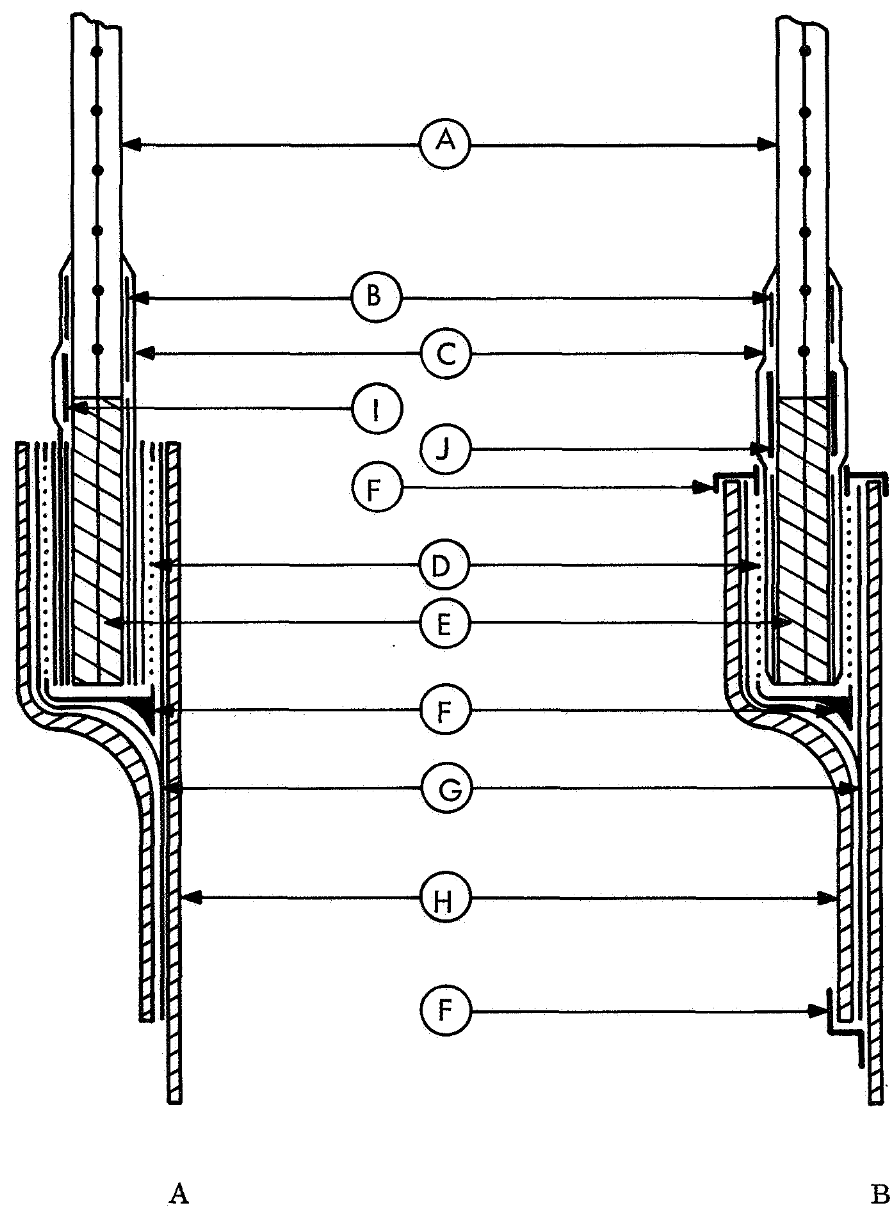


Figure 15. Schematic A, B, Cross Section of Transparent Window in Flexible Glass Cloth Panel

LEGEND OF CROSS SECTION OF TRANSPARENT WINDOW IN FLEXIBLE GLASS CLOTH PANEL (FIGURES 15A AND 15B

(A) - Silicone window with fiberglass reinforcement.

(B) - Silicone adhesive A-4000/epoxy 943 adhesive system at silicone/nitrile interface.

(C) - Nitrile rubber seal.

(D) - Fiberglass doily embedded in uncured nitrile rubber.

(E) - Cured nitrile anchorage flange.

(F) - Uncured nitrile rubber.

(G) - Nitrile cement.

(H) - Flexible fiberglass cloth.

(I) - Mylar ring in non-adhesion area of cured nitrile polymer sealant--pressure side only.

(J) - Mylar ring in non-adhesion area of cured nitrile polymer sealant--both pressure and non-pressure sides.

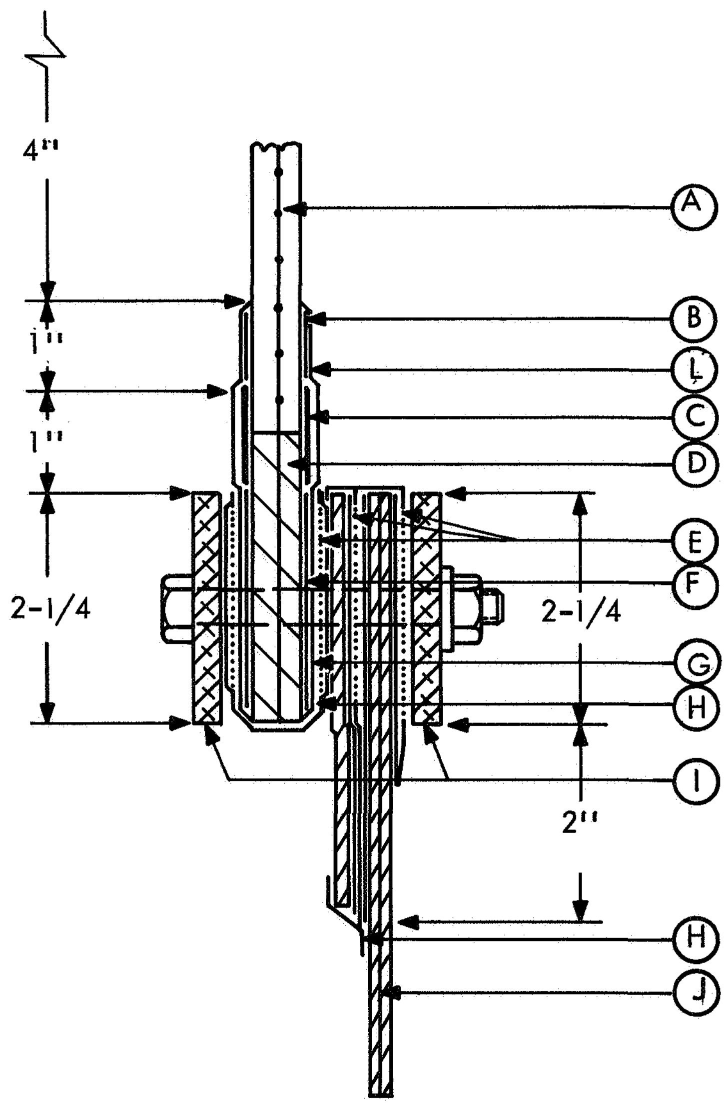


Figure 16. Schematic Cross Section of Transparent Window Attached to Flexible Glass Cloth Panel With Mechanical Clamp

LEGEND OF SCHEMATIC CROSS SECTION OF FILAMENT REINFORCED TRANSPARENT WINDOW ATTACHED TO FLEXIBLE GLASS CLOTH PANEL WITH MECHANICAL CLAMP (FIGURE 16)

(A) Silicone window with fiberglass reinforcement.

(B) Silcone adhesive A-4000/epoxy 943 adhesive system at silicone/nitrile interface.

(C) Mylar ring in non-adhesion area of cured nitrile polymer sealant-- both pressure and non-pressure sides.

(D) Cured nitrile anchorage flange.

(E) Fiberglass doilies embedded in uncured nitrile rubber.

(F) Nitrile cement.

(G) Cured nitrile rubber.

(H) Uncured nitrile rubber.

(I) Mechanical clamp.

(J) Flexible fiberglass cloth.

(L) Nitrile rubber seal.

TABLE 24. FILAMENT REINFORCED TRANSPARENT WINDOW HUMAN FACTORS OPTICAL AND PRESSURIZATION TESTS

Panel Number and Design		Before Pressurizing			Pressurized to 7.0 p.s.i.			After Pressurizing to 7.0 p.s.i. for 24 Hrs.			Hydrostatic Burst Pressure p.s.i.	Girth**** Wall Stress Lbs/Inch	Remarks
		6"	12"	24"	6"	12"	24"	6"	12"	24"			
No. 1	A*	3.0	3.0	3.0	4.0	4.0	4.0	**	**	**	-	63	** Failed after 2 hours at 7.0 p.s.i. Failure due to nitrile seal at edge pulling away from silicone matrix. Defective area approximately 1" long. Seal Fig. 7A
Design #4	B*	2.0	2.5	2.5	3.0	3.0	3.0						
(not aged)	C*	2.0	3.0	3.0	3.5	3.5	3.5						
Last legible number		2439	2439	2439	2439	2439	2439						
No. 2	A	3.0	3.5	4.0	3.5	4.0	4.0	**	**	**	-	63	** Failed after 2 hours at 7.0 p.s.i. Failure due to nitrile seal at edge pulling away from silicone matrix. Seal Fig. 7A
Design #1	B	3.0	3.5	4.0	3.5	4.0	4.0						
(not aged)	C	3.0	3.5	4.0	3.5	4.0	4.0						
Last legible number		8307	8307	2439	8307	2439	2439						
No. 3	A	3.5	3.5	4.0	3.5	4.0	4.0	**	**	**	-	63	** Failed after 20 minutes at 7.0 p.s.i. Failure due to nitrile seal at edge pulling away from silicone matrix. Seal Fig. 7A
Design #4	B	3.5	3.5	4.0	3.5	3.5	4.0						
(not aged)	C	3.5	4.0	4.0	3.5	4.0	4.0						
Last legible number		8307	2439	2439	8307	2439	2439						
No. 4 (wire)	A	2.0	2.0	2.0	**	**	**				-	63	** Failed immediately at 7.0 p.s.i. due to leak in seal. Seal Fig. 7A
Design #8	B	2.0	2.0	2.0									
(not aged)	C	2.0	2.0	2.0									
Last legible number		8307	8307	8307									
No. 5	A	3.5	3.5	3.5	4.0	4.0	4.0	-	-	4.0	-	63	Panel soap tested after 24 hours. No leaks. Seal Fig. 7B
Design #1	B	3.5	3.5	3.5	4.0	4.0	4.0			4.0			
(not aged)	C	3.5	3.5	3.5	4.0	4.0	4.0			4.0			
Last legible number		2439	2439	2439	2439	2439	2439			2439			
No. 6	A	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	22.0	198	Vertical filaments pulled out of nitrile polymer anchor ring. Seal Fig. 15A
Design #4	B	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5			
(not aged)	C	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5			
Last legible number		2439	2439	2439	2439	2439	2439	2439	2439	2439			
No. 7	A	4.5	4.5	5.0	4.5	4.5	5.0	4.5	4.5	5.0	29.0	261	Vertical filaments pulled out of nitrile polymer anchor ring. Seal Fig. 15B
Design #1	B	4.5	4.5	5.0	4.5	4.5	5.0	4.5	4.5	5.0			
(not aged)	C	4.5	4.5	5.0	4.5	4.5	5.0	4.5	4.5	5.0			
Last legible number		2439	3860	3860	2439	3860	3860	2439	3860	3860			
No. 8	A	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	26.0	234	Seal Fig. 15B
Design #1	B	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5			
Aged 1 week @100°C.	C	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5			
Last legible number		8307	8307	8307	8307	8307	8307	8307	8307	8307			
No. 9	A	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	23.0	207	Inside of window surface "fogged". Failure due to "doily" slipping out at top section. Window satisfactory. Seal Fig. 15B
Design #4	B	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5			
Aged 1 week @100°C.	C	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5			
Last legible number		3860	3860	3860	3860	3860	3860	3860	3860	3860			
No. 10 (wire)	A	2.0	2.0	2.0	2.5	2.5	2.5	**	**	**	-	63	** Failed after 4 minutes at 7.0 p.s.i. Failure due to steel wire pulling out of anchor strip. Seal Fig. 15B
Design #8	B	2.0	2.0	2.0	2.5	2.5	2.5						
(not aged)	C	2.0	2.0	2.0	2.5	2.5	2.5						
		6307	8307	8307	8307	8307	8307						
No. 11	A	2.5	2.5	2.5	2.5	2.5	2.5		-		59.0	531	No failure in window or clamp. Failure in test panel construction. Seal Fig. 15B
Design #4	B	2.5	2.5	2.5	2.5	2.5	2.5		-				
(not aged) Mech. Clamp	C	2.5	2.5	2.5	2.5	2.5	2.5		-				
No. 12	A	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	31.0	279	Leakage at seal. Silicone matrix broken at seal. Failure - filament pull out of anchor strip. Seal Fig. 15B
Design #8	B	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0			
Aged 1 week @100°C. Mech. Clamp	C	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0			
No. 13	A	3.0	3.0	3.0	3.0	3.0	3.0		***		40.0	360	No failure in window or clamp after 30 seconds hold at 40 p.s.i. Seal Fig. 15B
Design #1	B	3.0	3.0	3.0	3.0	3.0	3.0						
(not aged) Mech. Clamp	C	3.0	3.0	3.0	3.0	3.0	3.0						

* See Table 19 -- Phase I
** See Remarks
*** No failure but window fogged due to high humidity within test tank.
****Average measured inflated radius 9 inches.

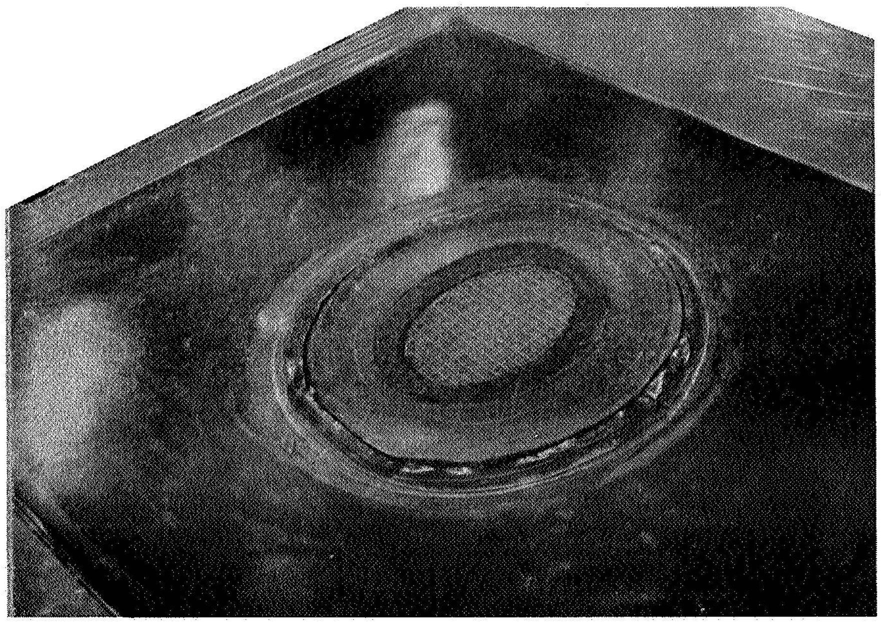


Figure 17. Transparent Window Cemented in Place on Flexible Glass Cloth Panel

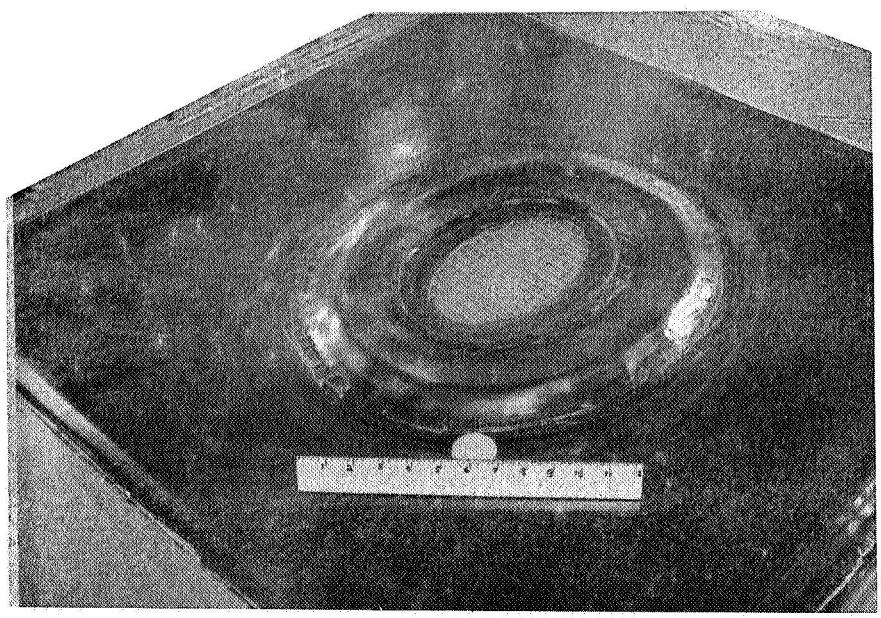


Figure 18. Completed Flexible Transparent Window/Panel Composite

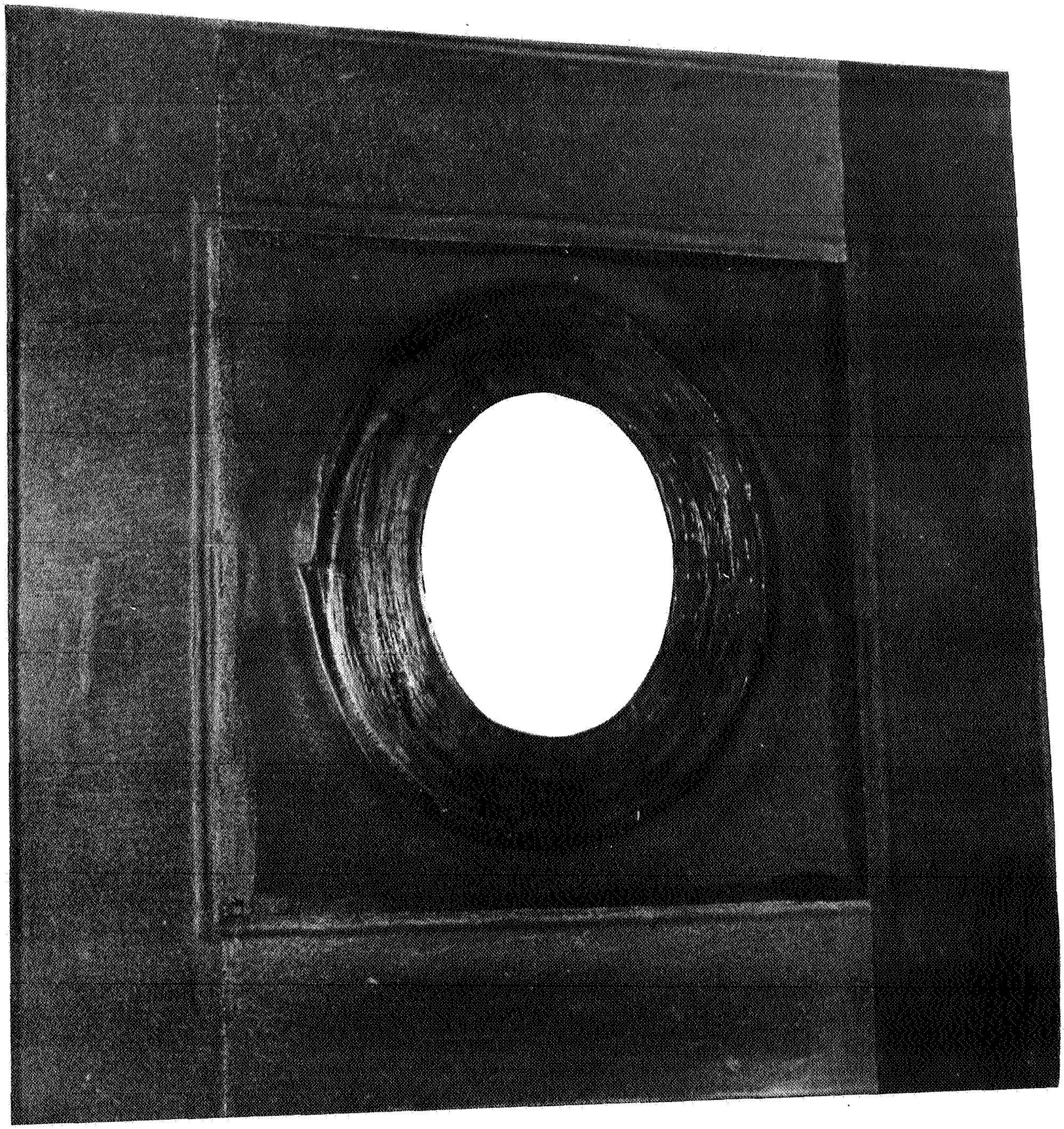


Figure 19. Reinforced Fiberglass Test Panel Prior to Attachment to the Pressure Chamber – Mechanical Window Attachment Concept

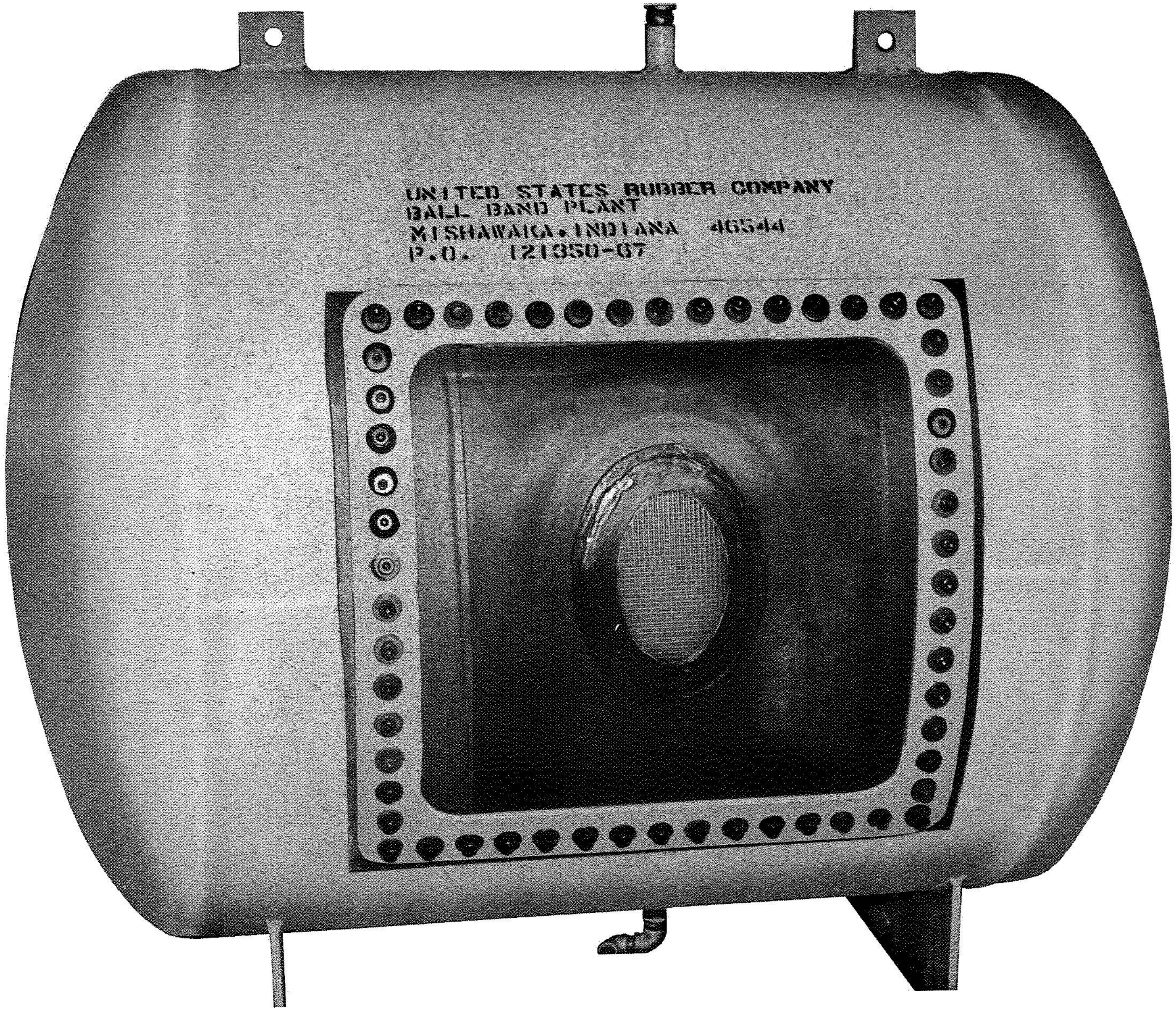


Figure 20. 48'' O.D. Pressure Chamber with Adhesively Bonded Window on Test

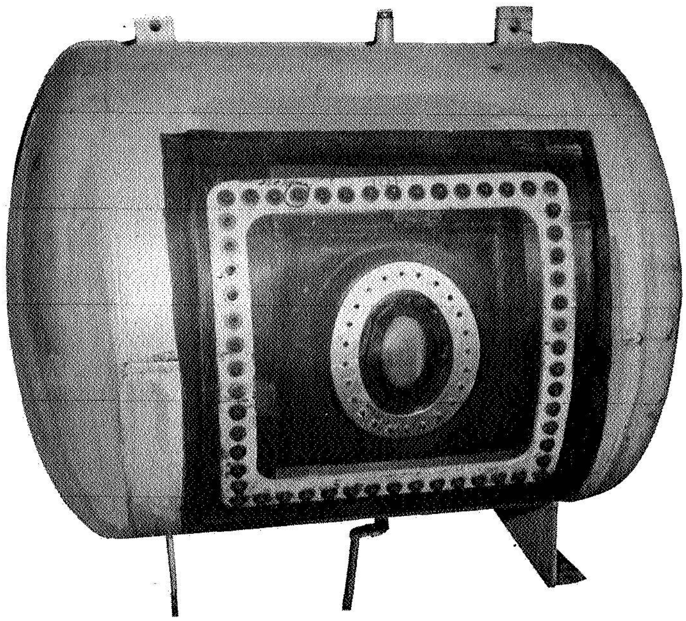


Figure 21. 48" O.D. Pressure Chamber with Mechanically Clamped Window on Test

The respective flexible window sections bulged relative to the peripheral anchorage support during pressurization. An estimate of the radius of curvature was calculated from measurements made of the arc length and chord length of the flexible window surface at slightly positive pressure (approx. 0.5 psi) and at 7.0 psi. The radius of curvature under 0.5 psi was 24". Under 7 psi internal pressure the girth window arc increased an average of 2% in length while the chord length shortened approximately 2%. This combined action resulted in a final pressurized radius of approximately 9 inches. This radius of curvature was then used to estimate the wall stress associated with the test pressures shown in Table 24. The stress was calculated using the expression Sg = Pr.

Pertinent information on panels shipped to NASA-Langley for further evaluation of Designs 1, 4, and 8 are shown in Table 25.

TABLE 25. DESIGN DETAILS FOR TEST PANELS FORWARDED TO NASA – LANGLEY FOR IN-HOUSE TESTING*

Panel Number	Design	Matrix	Reinforcement	Width "a"	Thickness	Required Modulus of Elasticity PSI (Min.)	Actual Modulus of Elasticity P.S.I.
S/N-1	1	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.100	0.189"	14**	615***
S/N-2	1	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.100	0.191"	13**	615***
S/N-3	1	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.100	0.195"	13**	615***
S/N-4	1	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.100	0.192"	13**	615***
S/N-5	4	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.040	0.191"	2**	615***
S/N-6	4	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.040	0.187"	2**	615***
S/N-7	4	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.040	0.189"	2**	615***
S/N-8	8	Dimethyl RTV Silicone	S–1 Steel Wire	0.200	0.170"	15**	615***
S/N-9	1****	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.100	0.193"	13**	615***
S/N-10	4****	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.040	0.189"	2**	615***

* All panels featured window seal shown in Figure 15B.
** Insignificant modulus of elasticity required at this laminate thickness.
***Typical Value.
****Mechanical clamp panel and window

PHASE III
FILAMENT WOUND STRUCTURE
INCORPORATING A FLEXIBLE WINDOW

This phase included the design, fabrication and experimental evaluation of three scale model filament-wound cylindrical chambers with hemispherical ends, each incorporating a flexible transparent window in the cylindrical section as shown in Figure 22. Each chamber was 18 inches in diameter and had a cylindrical section 13 inches in length. They featured ovaloid end closures with a polar fitting at each end. The polar fitting had an inside diameter of 4.0 inches to permit access to the inside of the chamber. The flexible window had a clear area of approximately 18 square inches and was attached to the cylinder wall using the window construction and window attachment selected from PHASE II. The window and attachment demonstrated the following capabilities:

(A) Window optical properties commensurate with the product standards established in PHASE I and PHASE II.

(B) One hydroproof pressurization cycle did not cause structural damage. A hydroproof pressurization cycle consisted of the following:

   (1) Pressurization to 28 psi ± 2 psi at the rate of 50 psi ± 20 psi per minute.

   (2) Held at 28 psi ± 2 psi for 1 minute.

   (3) Reduced pressure to 0 psi at the rate of 50 psi ± 20 psi per minute.

(C) 25 cycles of folding to a radius of 1 1/2" did not cause structural damage or weakening of the attachment by greater than 40 percent of the design strength.

The test program for the three chambers is shown in Table 26.

DESIGN OF FLEXIBLE FILAMENT WOUND STRUCTURE

The dimensions of the flexible filament-wound structure are shown in Figure 23. The cylinder portion of this structure with a diameter of 18.0 inches was 3/8 the scale of the proposed full scale cylinder diameter of 48.0 inches. The dome ends were contoured to yield an isotensoid ovaloid structure.

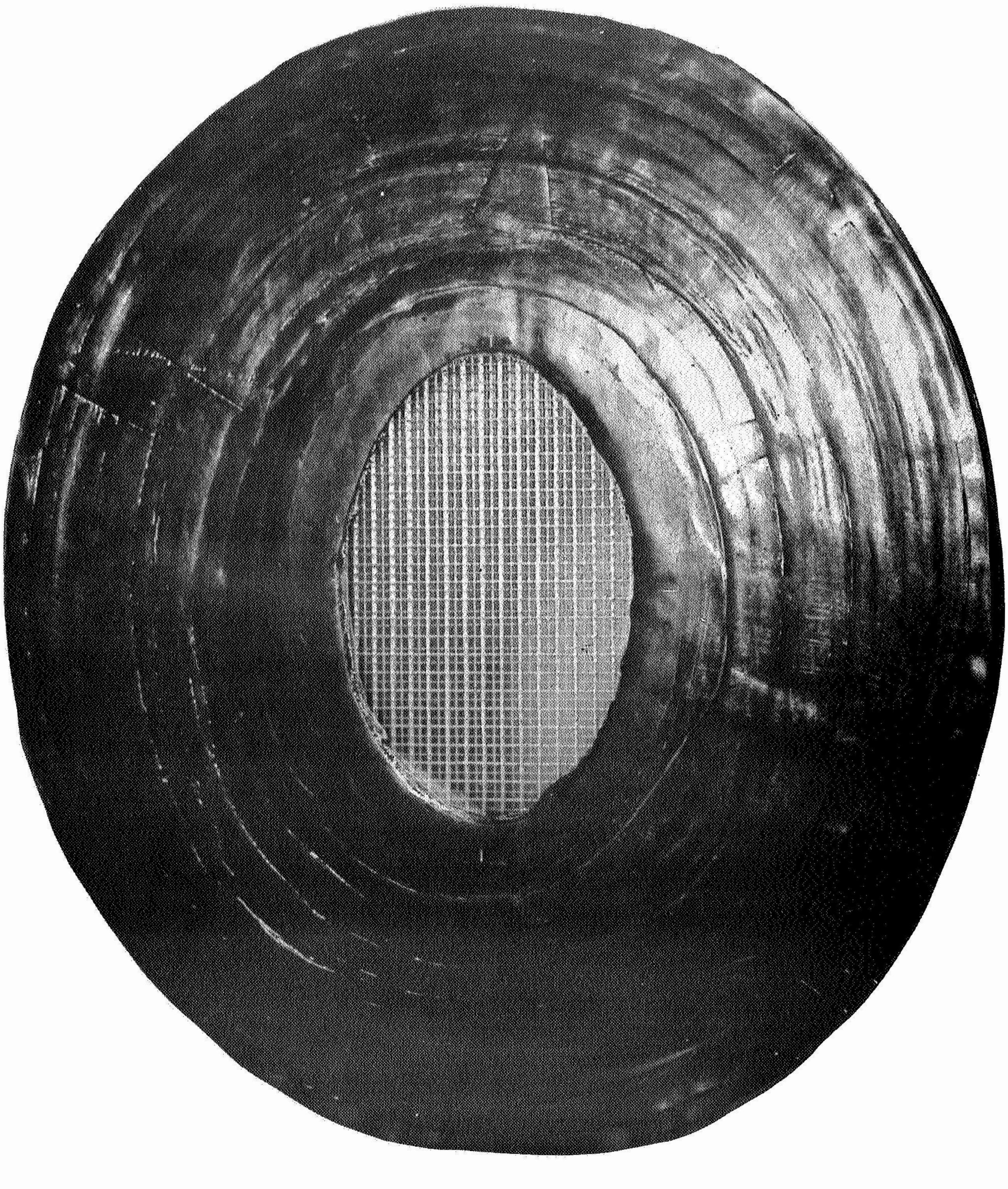


Figure 22. Reinforced Flexible Window for Attachment into 18" Filament-Wound SM-1 Chamber

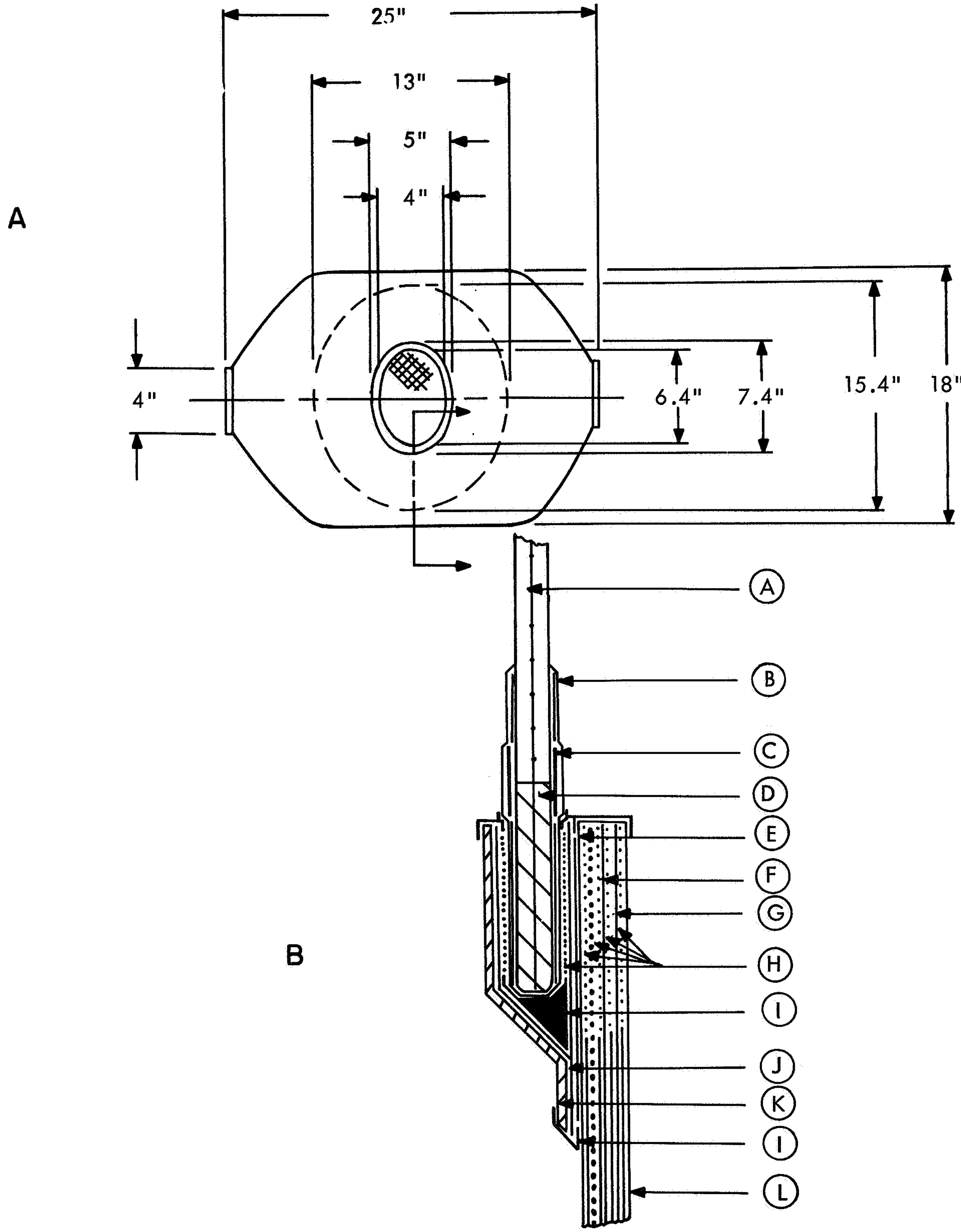


Figure 23. Schematic A, B, Structural Design of Scale Model Chamber S/M-1-1 thru S/M-1-3

LEGEND FOR SCHEMATIC STRUCTURAL DESIGN OF CROSS SECTION OF TRANSPARENT WINDOW IN SCALE MODEL CHAMBER S/M-1-1 THRU S/M-1-3 FIGURE 23B

(A) Silicone window with fiberglass reinforcement.

(B) Silicone adhesive A-4000/epoxy 943 adhesive system at silicone/nitrile interface.

(C) Mylar ring in non-adhesion area of cured nitrile polymer sealant--both pressure and non-pressure sides.

(D) Cured nitrile anchorage flange.

(E) Girth ply of elastomer impregnated glass roving.

(F) First axial ply of elastomer impregnated glass roving.

(G) Second axial ply of elastomer impregnated glass roving.

(H) Fiberglass doilies embedded in uncured nitrile rubber.

(I) Uncured nitrile rubber.

(J) Nitrile cement.

(K) Flexible fiberglass cloth.

(L) 2 oz. nylon coated with nitrile rubber.

TABLE 26. TEST PROGRAM FOR SCALE MODEL CHAMBERS (S/M-1)
3/8 Scale Model Chambers with One Window

Chamber Number	Proof Pressure Percent of Burst	Pressure Medium	Test Pressure	Test Time	Failure Pressure	Window Surface Finish	Window Optical Quality Test	Percent Glass Clarity
1	-	--	Unpres-surized	-	-	*	*	*
1	80%*	Water	28 psi	1 min		-	-	-
1	40%*	Air	14 psi	1 hr		-	-	-
1	20%	Air	7 psi	8 hrs	-	*	*	*
1	-	Water	To failure	-	*	-	*(1)	-
2		--	Unpres-surized			*	*	*
2	80%*	Water	28 psi	1 min		-	-	-
2**	60%	Water	21 psi	1 min		-	-	-
2	20%*	Air	7 psi	8 hrs		*	*	*
2	40%*	Air	14 psi	1 hr, 4 cycles		-	-	-
2	20%	Air	7 psi	8 hrs		*	*	*
3	-	--	0	-		*	*	*
3	80%*	Water	28 psi	1 min	-	-	-	-

* Tests performed at ambient conditions.
** Where applicable chamber folded 25 cycles at room temperature to no less than 1/4" radius fold and then proof tested to 60% of design burst pressure.
(1) Performed on window material after burst test.

The design of the finished filament-wound structure provided for the following:

(A) A 2 oz. coated nylon air impermeable inner liner.

(B) One double axial ply of elastomer impregnated glass roving (240 ends per inch per ply) wound at 11.5°.

(C) One girth ply (240 ends per inch per ply) wound at essentially 90°.

(D) One over-all ply of an elastomeric outer covering.

(E) Filament-wound "doily" reinforcements circumscribing the area in the cylinder wall which was cut out prior to attachment of the flexible window.

(F) Two aluminum end fittings to provide access to the inside of the completed structure.

DESIGN DETAIL

Pressure Vessel Construction

This pressure vessel was primarily designed to be flexible, and to provide means for pressurizing the attached flexible windows to at least their designed pressure of 35.0 psi.

The wall stress in the full scale cylinder at the design pressure of 35 psi (safety factor of 5 x 7 psi) was previously established at 840 pounds per inch of girth width and 420 pounds per inch of circumference. It would have been prudent to evaluate the proposed attached flexible window in the cylinder of the 3/8 scale model pressure vessels under these ultimate stresses. However, since the window matrix had a proposed ultimate "blow-out" pressure of 35 psi, the test pressure was limited to approximately 35 psi. The wall stress at 35 psi was calculated to be 315 pounds per inch of cylinder length and 158 pounds per inch of circumference.

The criteria used for establishing the wall stress to be used for the scale model pressure vessels, was based upon use of a production type winding ribbon having a roving end count of 240 ends per inch. A great circle wind was used for applying the axial windings. This winding pattern required a double ply to produce a completely balanced structure. Therefore the minimum possible axial windings using this design criteria was 2 single plies of axial windings wound at 11.5°, with each ply supplying 240 ends per inch per ply. Similarly one girth ply was used incorporating a winding ribbon having 240 ends per inch width and applied at approximately 90°.

The wall stress potential for these two winding patterns was determined as follows:

Axial Wall Stress

$$s_a = n_a e_a \cos^2 \phi \, t_e \qquad (6)$$

where s_a = axial wall stress per inch of circumference

n_a = number of single axial plies = 2

e_a = ends per inch width of axial ribbon = 240

ϕ = winding angle = 11.5°

t_e = working glass end tensile = 5.0 pounds

$s_a = (2)\ (240)\ (0.980)^2\ (5.0) = 2304$ pounds/inch

$s_a = 2304$ pounds/inch

Girth Wall Stress

$$s_g = n_g e_g \sin^2 \theta \, t_e \qquad (7)$$

where s_g = girth wall stress per inch of cylinder

n_g = number of single girth plies = 1

e_g = ends per inch width of cylinder = 240

θ = winding angle 90°

$s_g = (1)\ (240)\ (5.0) = 1200$ lbs/inch cylinder

The axial plies also supplied girth reinforcement s_{ga} to the extent:

$$s_{ga} = n_a e_a \sin^2 \phi \, t_e \qquad (8)$$

$s_{ga} = 2\ (240)\ (0.199)^2\ (5.0) = 95.0$ lbs/inch

Therefore total girth stress s_{gt} available from the winding pattern was:

$$s_{gt} = s_g + s_{ga} \text{ lbs/inch cylinder} \qquad (9)$$

$s_{gt} = 1200 + 95 = 1295$ lbs/inch

The respective calculated pressure failure strengths based on the available wall stress were as follows:

Girth

$$s_{gt} = Pr \tag{10}$$

where P = maximum pressure – psi

r = radius of vessel – inches

$$P = \frac{s_{gt}}{r} = \frac{1295}{9} = 144.0 \text{ psi}$$

Axial

$$s_a = \frac{Pr}{2} \tag{11}$$

$$P = \frac{2s_a}{r} = \frac{2(2304)}{9} = 512.0 \text{ psi}$$

Therefore the limiting design test pressure for the filament-wound pressure vessel was 144.0 psi.

The inner liner consisted of one ply of coated 2 oz. square woven nylon fabric which was applied to the prepared sand/PVA mandrel. The nylon fabric was then cured with one ply of an elastomeric liner.

The outer covering consisted of a single ply of an elastomeric material applied after all filament-winding operations were completed.

Reinforcement for Window Cut-out in Cylinder

An ellipsoid having a ratio of minor to major axis of 1:1.4 was chosen for the design of the window cut-out. This cut-out involved cutting through all of the axial and girth windings around the periphery of the cut-out. In order to maintain continuity of stress transfer through these cut filaments, several filament-wound "doilies" encircling the cut-out were bonded between winding plies.

The doilies were wound at 720 ends/inch width using single end elastomer preimpregnated glass yarn.

The reinforcement structure used for the ellipsoid cut-out is shown in Figure 24. The filaments around the window cut-out were cut and removed after completing the cure of the filament-wound vessel.

DESIGN OF TRANSPARENT WINDOW

Design 1 was used to fabricate the transparent window for all three scale model chambers evaluated in PHASE III.

Details of design 1 can be found on pages 45 and 49, and Table 27.

TESTING

The test plan shown in Table 26 was applied to the three scale model chambers as follows:

Scale Model Chamber 1-1

The results of the human factor tests performed on scale model chamber 1-1 shown in Figure 25 are listed in Table 28.

The results of the pressure tests are shown in Table 29.

The initial window installed in SM-1-1 failed prematurely at 27 psi due to a seal leak at the silicone/nitrile rubber interface. This leak was repaired using silicone adhesive A-4000 on the silicone and epoxy 943 adhesive on the nitrile rubber seal. The chamber was repressurized and failure occurred at 65 psi which is equal to a girth stress of 585 pounds/inch. Examination of the transparent window showed no apparent damage. Failure occurred at the window seal interface.

The entire window was removed and a new window adhesively bonded to the flexible wall structure. This new window failed in the seal/window interface at 57 psi which is equal to a girth stress of 513 pounds/inch. An analysis of this latter failure indicated that the window replacement repair procedure severely stiffened the fabric glass structure within the peripheral area immediately adjacent to the transparent window. During the latter stages of pressurization of the chamber this excessive stiffening caused unusual bending strains at the junction of the chamber window cut-out and the flexible window. This condition caused a premature tensile failure in the window matrix at the junction of the window seal and the window matrix.

Figure 24. Flexible Filament Fiberglass S/M-1 Pressure Chamber Showing Reinforced Opening for Flexible Window

TABLE 27. DESIGN DETAILS OF SCALE MODEL CHAMBERS*

Chamber Number	Design	Matrix	Reinforcement	Width "a"	Thickness	Required Modulus of Elasticity PSI. (Min.)	Actual Modulus of Elasticity P.S.I.
S/M-1-1	1	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.100"	0.188"	14**	615***
S/M-1-2	1	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.100"	0.190"	14**	615***
S/M-1-3	1	Dimethyl RTV Silicone	G-1 "S" Fiberglass	0.100"	0.192"	13**	615***

* All chambers featured window seal shown in Figure 15B.
** Insignificant modulus of elasticity requirement at this laminate thickness.
*** Typical Value.

TABLE 28. HUMAN FACTOR TESTS (S/M-1-1)

Scale Model Chamber Test Condition	Human Factor Rating	
	Test Variable	Rating *
Unpressurized	A (see Table 19)	2.5**
	B	2.5
	C	2.5
	Last Legible Number	8307
Pressurized at 7.0 psi. air.	A	2.5**
	B	2.5
	C	2.5
	Last Legible Number	8307
After being pressurized at 7.0 psi air-8 hrs. ***	A	3.0**
	B	3.0
	C	3.0
	Last Legible Number	8307

* Eye chart 6 inches behind window. Observation made with eye positions 3" to 24" from window.
** Average rating for all eye positions.
*** This test followed all of the hydropressure tests except final pressure to failure test.

Figure 25. NASA Transparent Window in S/M-1 Filament-Wound Chamber

TABLE 29. PRESSURE TESTS (S/M-1-1)*

Scale Model Chamber Test Condition	Remarks
Pressurized to 28 psi (water), held at 28 psi for 1 min. then depressurized to 0 psi.	No failure
Pressurized to 14 psi (air), held at 14 psi air for 1 hr. then depressurized to 0 psi.	No failure
Pressurized to 7 psi (air), held at 7 psi for 8 hrs. then depressurized to 0 psi.	No failure
Pressurized with water to failure at 10 psi/min.	Failure occurred at interface of flexible seal and transparent window at 27 psi. (Girth stress 243 lbs./inch). This leak was repaired and the chamber repressurized to failure. In the second pressure test, failure occurred at 65 psi. (Girth stress 585 lbs./inch). Failure again occurred at the window-seal interface.

* See Figure 25

Discussion of Test Results on Scale Model Chamber 1-1

The human factors rating must be used as a "relative" rating within each test type. This rating was designed to denote changes in the optical qualities of the transparent window when subjected to the various test conditions. Therefore the numerical ratings for the chamber windows may not exactly match the ratings for the similar window structure tested previously as panels in a different test fixture.

Review of Table 28 shows that there was no perceptible change in the human factor ratings between unpressurization and pressurization at 7.0 psi. The slightly poorer rating shown for the window after 8 hrs. held at 7.0 psi reflects some slight change due to the previous pressure tests. However, even the rating of 3.0 in each category of inspection qualifies this window as acceptable for general observation purposes.

Scale Model Chamber 1-2

The results of the human factor test performed on scale model chamber 1-2 are shown in Table 30.

TABLE 30. SCALE MODEL CHAMBER (SM-1-2) HUMAN FACTOR TEST

Scale Model Chamber Test Condition	Test Variable	Rating
Unpressurized.	A	3.0
	B	3.0
	C	3.0
	Last Legible Number	8307
Pressurized at 7.0 psi air.	A	3.0
	B	3.0
	C	3.0
	Last Legible Number	8307
After being folded 25 cycles to 1 1/2" radius and after being pressurized at 7.0 psi air-8 hrs. (second occurrence).	A	3.0
	B	3.0
	C	3.0
	Last Legible Number	8307
Pressurized 5 cycles at 14 psi air, held at 14 psi for 1 hr. then reduced pressure to 0 psi plus 8 hrs. at 7.0 psi air (third occurrence).	A	3.0
	B	3.0
	C	3.0
	Last Legible Number	8307

The results of the pressure tests are shown in Table 31.

TABLE 31. PRESSURE TESTS (S/M-1-2)

Scale Model Chamber Test Condition	Remarks
Pressurized to 28 psi water, held at 28 psi for 1 min, then de-pressurized to 0 psi.	No failure
Pressurized to 21 psi* water, held at 21 psi for 1 min, then de-pressurized to 0 psi.	No failure
* This test followed folding chamber 25 cycles to 1 1/2" radius thru window. (See Figure 26.)	

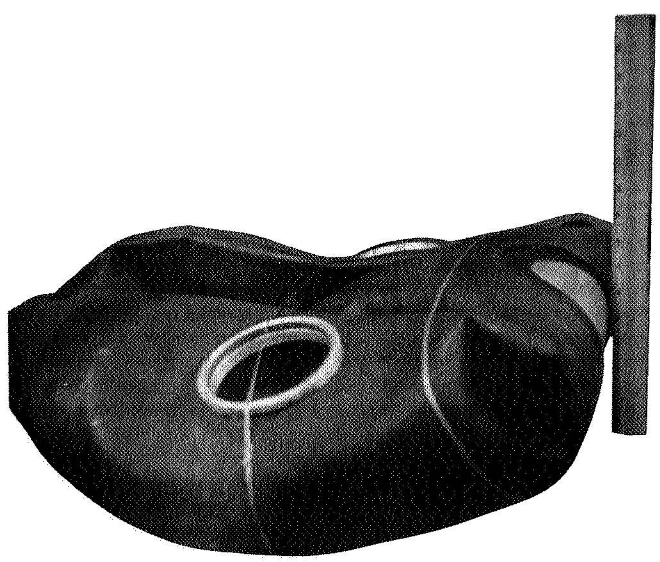


Figure 26. NASA Transparent Window in Folded S/M-1-2 Filament Wound Chamber

Discussion of Test Results on Scale Model Chamber 1-2

The human factor rating showed no perceptible change in the optical properties of the test window after being subjected to the noted tests. The folding test was limited to a bending radius of 1 1/2" due primarily to the stiffening of the window attachment system. This stiffening was especially manifest because the full scale window attachment system (applicable to 48" diameter cylinder) was incorporated to attach the window to the 18" diameter cylinder wall. The overall effect of this attachment would be substantially more flexible as the window size is increased.

This test again demonstrated that the test window was optically acceptable for general observation, and that it demonstrated the structural integrity required of this window in the envisioned space structure.

Scale Model Chamber 1-3

This scale model chamber was hydroproofed at 28 psi for one minute without failure and then depressurized. This chamber was then forwarded to the contractor as directed.

CONCLUSIONS

Based upon the work conducted in the course of NASA contract NASI-5524 and the data contained within this report, the following conclusions may be drawn:

(A) A transparent, filament reinforced/polymeric composite capable of being utilized as a flexible window in space vehicles can be fabricated.

(B) A polymeric frame of 2" minimum width must be utilized in conjunction with the reinforced/polymeric panel for anchoring the ends of the filaments.

(C) The reinforced/polymeric, transparent window may be attached to a simulated space structure utilizing adhesive or mechanical means.

(D) Satisfactory materials for use in fabricating transparent, flexible windows consist of glass filaments (as reinforcements) embedded in a matrix of a castable dimethyl RTV silicone.

(E) Reinforced/polymeric transparent panels can be fabricated to withstand a pressure of 7 psi with a safety factor of 5.

RECOMMENDATIONS

During the course of our work in the development of a reinforced polymeric transparent composite, for use as a flexible window in space vehicles, several areas of the problem worthy of further study became apparent. The areas felt worthy of further study are here advanced for consideration as extensions to the work initiated in contract NASI-5524.

(A) Evaluate transparent polymers for effects of mold charge and time-temperature-pressure parameters on their ultimate physical and optical characteristics.

(B) Evaluate materials and methods for preimpregnating reinforcement fibers used in flexible, transparent window panels. Preimpregnation would improve the ease of handling fibers; reduce air entrapment in the interstices of the twisted fibers; and improve adhesion between the fibers and the matrix.

(C) Evaluate the plating of elastomers - as in one way, see through mirrors.

(D) Evaluate sectionalized metal clamping devices for replaceable window structures.

(E) Consider polymers having higher tensile strengths but lower initial light transmission qualities than those which have been evaluated.

(F) Develop methods of fabricating complete cylindrical sections of transparent composites.

(G) Evaluate the application of "Photoelastic Techniques" to the study of strain patterns in the reinforced polymeric transparent panels. The photoelastic technique utilizes polarized light and the birefringence of materials to determine the strain pattern in an object. Although some materials are sufficiently birefringent and uniform, strain patterns can be determined directly by transmission or reflection methods, windows made of silicone or other low birefringence materials would require coating with a thin layer of a photoelastic material or the use of model techniques. Characteristics of the transparent flexible windows which may be evaluated utilizing the "photoelastic technique" are:

(1) Examination of uniformity of residual strains - if any.

(2) Examination of strain distribution in pressurized, non-reinforced windows as a function of geometry.

(3) Examination of strains in pressurized, reinforced windows as functions of geometry and reinforcement design.

(4) Determination of reinforcement efficiency as a function of materials and design.

(5) Examination of adhesion of reinforcement material to polymer.

(6) Determination of strains induced as a function of fastening method and design (adhesive or mechanical).

(7) Stress distribution as a function of strain and time.

(H) Evaluate improved adhesive systems for anchoring steel wire reinforcement. Also evaluate smaller diameter steel wire filaments as reinforcement for the matrix of a transparent window.

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Mishawaka, Indiana, 9 April 4, 1967. 10 C √

ABSTRACT

The objective of the work conducted on NASI-5524 study was to determine the technical feasibility of producing a flexible, reinforced transparent composite for use as a window in space vehicles or shelters.

Eight polymers selected from four generically different types were evaluated as the matrix for the composite.

Two glass, one steel, and one synthetic filament were evaluated as reinforcement media.

RTV silicone and polyester type polyurethane polymers were selected for continued evaluation in combination with glass or steel filaments.

Work was initiated utilizing five basic reinforcement netting patterns and this was later expanded to ten netting patterns. Adhesive and mechanical means of installing resultant windows in simulated space structure panels were evaluated. Simulated space structure panels with windows installed, utilizing adhesive and mechanical methods, were tested under a sustained pressure of 7.0 p.s.i. for 24 hours followed by pressurization to burst.

Filament-wound cylindrical chambers with hemispherical ends and incorporating a flexible transparent window of dimethyl silicone matrix and S glass reinforcement in the cylindrical section were hydroproofed at 28 psi at a pressurization rate of 50 psi ± psi per minute.